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AN ELEMENTARY STUDY OF THE BRAIN

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TORONTO

AN ELEMENTARY STUDY OF THE BRAIN

BASED ON THE DISSECTION OF THE BRAIN OF THE SHEEP

BY

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ILLUSTRATED WITH PHOTOGRAPHS AND DIAGRAMS BY THE AUTHOR

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PREFACE

THE introduction into the purely academic curriculum of an anatomical study of the brain, even as a higher course in zoölogy, presents many difficulties both to student and instructor. Its presentation, as differing from that in the professional school, must be necessarily of an elementary character — a necessity offering many obstacles with a subject which is essentially advanced. In the preparation of a textbook for such a course, neither the complexities of cerebral structure, nor the confusion of the associated nomenclature, can be successfully evaded. Yet the average academic student, only too often possessed of no especial interest in this department of science, is not only unschooled in anatomical research and terminology, but is likewise wholly unfamiliar with the principles upon which they are based.

To avoid these difficulties, as far as practicable, has been, then, the underlying motive in providing for the beginner this very simple introduction to the anatomy of the human brain, using the brain of the sheep, because of its general availability, relative simplicity, and practical identity to that of man, as the subject for dissection and the basis for comparison. The advantages of actual dissection are obvious; the book is, primarily, a laboratory manual for the student himself. It is designed, however, to be rather more than a manual — to be, if possible, a unit study of the brain, of a strictly elementary nature. To this end the subject has been approached largely from the biological standpoint, not only in the chapters briefly reviewing the development of the brain in the race and in the human individual, but by constant reference throughout to the more fundamental conceptions of nervous structure and evolution. Moreover, the interdependence of cerebral anatomy and physiology, and their close alliance with psychology, make it essen-

tial that the physiological and psychological aspects freely supplement the purely anatomical, as a most valuable aid in the interpretation of structure, the stimulation of interest, and the retention of fact.

To simplify the nomenclature, without sacrifice of accuracy, has been hardly possible ; the names employed are, therefore, those from both the older terminology and the Basel association nomenclature (BNA), which in the author's opinion will be easiest acquired and remembered by the student. In most cases the terms descriptive of the brain of the sheep have been borrowed from the human, rather than from any mammalian, nomenclature, inasmuch as an understanding of the former, from which the latter is but an outgrowth, is the objective of this book. While in general the only names given in English are those commonly used in that form, the etymology of all those which appear in technical form is to be found in the footnotes ; moreover, as far as is possible, the complete BNA system has been presented, either as the name given or bracketed thereafter, that there may be a basis for further study and comparison with texts employing exclusively the newer terminology.

The author lays little claim to originality for the subject matter of the text, and has avoided a necessarily free scattering of references by grouping his sources as a bibliography, to which it is hoped the student will constantly refer for more detailed and conclusive information. If, indeed, this "brain primer" may but lay the foundation for further research in the vast field of nervous science, it will have fully attained its object.

To the authors whose works are listed in the bibliography, the writer wishes to make grateful acknowledgment, and to express his deep appreciation to Professor J. H. Gerould, of the Biological Department of Dartmouth College, and to Dr. C. C. Stewart, Professor of Physiology in Dartmouth Medical School, for their interest and valuable contribution in the preparation of this book.

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I

PHYLOGENY

By means of its nervous system, the animal organism regulates and coördinates the various portions of its body, and comes into communication with its environment, receiving impressions from without and acting upon them in accordance with its native endowment, and, in the higher animals at least, with the dictates of its individual experience. In low forms, therefore, the nervous structures are found upon the exterior of the body, affording the animal direct contact with those objects in the world about it from which its various stimuli are received and to which it must react. The very lowest organisms, made up of undifferentiated protoplasm,[1] which assumes all the functions of the body without specialization, cannot, however, be said to possess distinct nervous tissue. These animals react as a whole, a condition found in the protozoa and sponges. With the differentiation of the various parts into primary systems, certain cells are set apart for the reception of stimuli, and become, therefore, true nerve cells. From their position on the exterior of the body, these cells send slender processes inward to communicate with the processes

[1] Gr. *prōtos*, first, and *plassein*, to form; first thing formed.

of other cells. These processes are rudimentary nerve fibers; the essential character of the neurone,[1] consisting of a cell body and its processes, is therefore seen at an early stage.

The neurones are the units of structure of the nervous systems of all animals. By the grouping, or centralization, of the cell bodies into definite masses (ganglia)[2] and by the collection of the processes into well-defined bundles (tracts), all degrees of development are attained in more or less regularly increasing complexity, from the primitive diffuse system first appearing in the lowest metazoa to the intricate nervous mechanism of man. The most important of the ganglia becomes the brain. The nerve processes become the two great fiber systems: the afferent,[3] carrying impulses from the receptive apparatus to the brain; the efferent,[4] carrying impulses from the brain to the muscles and glands. The primitive surface cells become the specialized organs of the different senses, and the nerve cells themselves become altered in shape and character in accordance with the particular function of that part of the nervous system in which they are found. And, lastly, as each species exhibits in structure the characteristics of its stage in the evolution of the animal kingdom, so do its habits, activity, and general behavior correspond to the peculiarities of its nervous equipment.

The invertebrates exhibit two very important steps in this process of evolution — the withdrawal of the afferent system from its superficial position to the interior of the body, and the clumping of the nerve cells, which, with their nerve processes or fibers, have heretofore been uniformly distributed throughout one layer, into definitely localized ganglia. Thus, the tangled network of nerve fibers in the

[1] Gr. *neuron*, nerve.
[2] Gr. *ganglion*, knot.
[3] Lat. *afferens*, carrying to.
[4] Lat. *efferens*, carrying from.

lower cœlenterates is supplemented in the medusa by a continuous ring around its bell — the first evidence of a special apparatus affording coördination between the various parts of the organism. This ring, communicating with the exterior by fibrous networks on the inner and outer sides of the bell, constitutes a very simple central nervous system for the animal. While the superficial position of the afferent system becomes somewhat lost in the higher medusæ, by the sinking in of the sensory cells which have made up the primitive receptive apparatus on the surface (the nervous epithelium), it is in the lower worms that this process becomes complete. So far, conduction of impulses is indiscriminate, that is, is carried by the fibers in all directions from the point of stimulation, its intensity depending on the strength of the stimulus. Now the system consists of two bundles of parallel nerve fibers, the lateral nerve cords, running along either side of the body beneath the muscle layer, and connecting with the exterior by a tangled mass of cells and fibers. These long fibers mark a distinct advantage over the diffuse system, by affording much more rapid and precise conduction between more distant portions of the animal.

Low members of the arthropod and mollusk groups are but little advanced over the condition of the flatworms, the nerve cords lying on the ventral side of the body, diffusely connected by intervening strands, the cell bodies being scattered for the most part among the fibers. In the higher worms, the lateral cords and their transverse connections are found as a double cord in the mid-ventral line; while enlargements corresponding to the body segments occur at definite intervals on the cord. In these enlargements are grouped the ganglion cells of each segment, which, with the transverse bundles passing across between, give the whole a ladder-like appearance. In these ganglia the connections

between the afferent and efferent neurones are now made, resulting in still more specialized and exact reaction to stimulation. The nervous system is still a ring (or at least a ring drawn out lengthwise), but these animals are bilaterally symmetrical and move in one direction. It is, therefore, only natural to suppose that the sensory endings and corresponding nervous structure should become more highly developed at the forward end. Certainly in the higher worms and arthropods the anterior ganglionic swellings become much larger than the others, especially those just under and over the œsophagus — the subœsophageal and supraœsophageal ganglia, respectively. The latter is distinctly analogous to a primitive brain, and is termed the cerebral[1] ganglion. It is not to be supposed, however, that it controls the ganglia behind it; rather, it governs the movements of the anterior segment, and the other segments must follow, though relatively independent. Even in the highest invertebrates, as the crayfish, which has several of its anterior ganglia fused together into one large cerebral mass, and the many parts of its body specialized for different functions, separation of this "brain" from the rest of the body does not prevent the limbs from carrying on their accustomed activities, although there is less coordination and they may act at cross purposes with each other. The cerebral ganglion of the higher arthropod has, therefore, some influence over the remaining ganglia, and seems to be, moreover, the center of spontaneous activity of the animal; while the remaining ganglia, made up of cells whose fibers supply the separate appendages and other functioning parts, still seem to be centers of motor energy for their respective regions of distribution.

The nervous system of the vertebrates is to be distinguished from that of the invertebrates by three important

[1] Lat. *cerebrum*, brain.

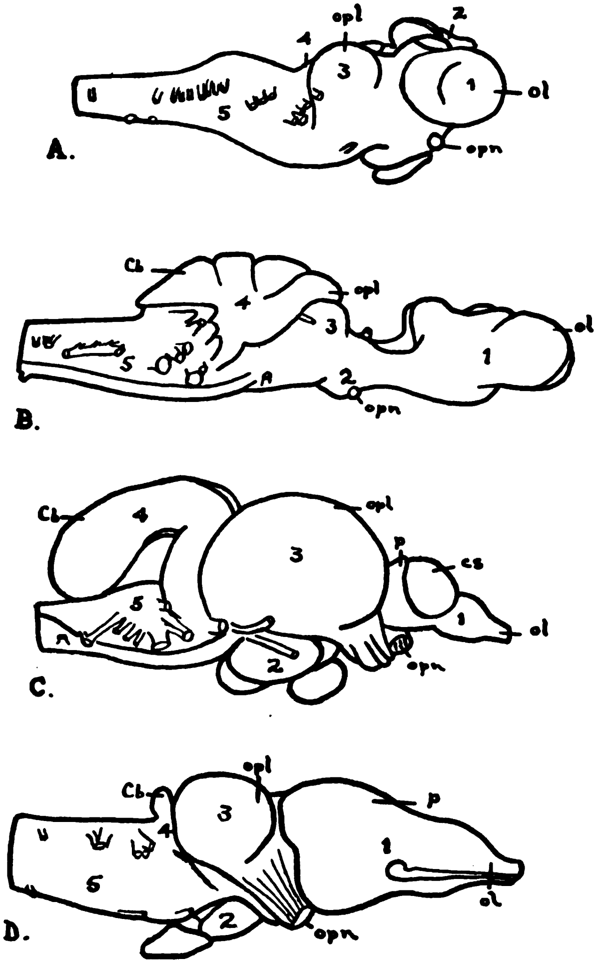


Fig. 1.—Wax Models of Vertebrate Brains

A. Lamprey eel	1. Forebrain	cb, cerebellum
B. Dog fish	2. Interbrain	cs, corpora striata
C. Salmon	3. Midbrain	ol, olfactory lobe
D. Frog	4. Hindbrain	op l, optic lobe
	5. Afterbrain	op n, optic nerve
		p, pallium

characteristics: first, the system lies in the middle line on the dorsal surface of the body; second, the entire central portion of the system is hollow or tubular; and third, a definite brain is always present. In regard to the first of these, there is a tendency for the nerve cords to leave the ventral for the dorsal side in some of the lower worms, and, in the higher invertebrates, many of the transverse connections are found dorsal to the digestive tract. Quite possibly, however, such a radical step can be only explained by the assumption that at some stage in evolution the whole animal turned over on its back. The second characteristic, the formation of a central canal, is explained by the ontogenetic [1] development of the nervous system peculiar to the vertebrates, which is to be more fully described in the next chapter. As to the third, the primitive swelling of the anterior ganglion, and the fusion of other ganglia with it, already considered, are here carried on to a higher degree, the primitive brain becoming divided into three hollow vesicles.[2] These constitute the forebrain, midbrain, and hindbrain, and from them arise all parts of the brain of each vertebrate class.

As this chapter is intended only as a brief summary of the evolution of nervous structure, the detailed anatomy of the many different vertebrate brains cannot be presented; only the most general description of the important steps will be given. The brain of the lowest vertebrates is essentially a series of highly developed centers for those senses upon which these animals depend for knowledge of the world about them. The possession of such a sense organ as the eye, which is excited by objects at a distance from the body, furnishes a greatly increased environment, and necessitates

[1] Gr. *ōn*, being, and *gonos*, generation; growth in the existing individual.

[2] Lat. *vesica*, bladder or sac.

a far greater complexity of nervous connections, especially from the visual center to the more fundamental mechanisms controlling the animal's activity. In general, whenever one or more of the sense organs is found to be considerably developed in a particular animal, that part of the brain receiving fibers from that organ is proportionately developed. Likewise, the efferent fibers from this center to other parts of the nervous system are greatly multiplied, and the importance of this special system in regulating the animal's behavior is correspondingly increased.

The cerebrum of the fish, though the lowest of the series, and very small in proportion to the size of the body, is greatly advanced over the cerebral ganglion of the highest invertebrates. Many of the enlargements and projections from the surfaces of its brain give promise of the more intricate and specialized development of the higher forms, although the three main divisions are easily made out. The walls of the forebrain are greatly thickened, encroaching on the cavities, and forming the cerebrum; this portion of the brain is largely concerned with the sense of smell in the lower vertebrates, and gives off large prolongations from its anterior end, which constitute the olfactory [1] lobes. Behind these lobes are seen the optic nerves, running from the eyes to the midbrain, where they end in the primary organ of sight, the optic [2] lobes, a pair of rounded elevations developed from the dorsal wall. These lobes, being the highest center for the important sense of sight, are probably the dominant part of the whole nervous system for these lower vertebrates. The hindbrain becomes differentiated principally into a large dorsal swelling, the cerebellum.[3] This organ is thought to govern muscular coördination and equilibrium in all species, and so is relatively well-developed in these animals,

[1] Lat. *olfacere*, to smell. [2] Gr. *opsis*, eyesight, seeing.
[3] Lat. *cerebellum*, little brain.

which exhibit great activity. The remainder of the hind-brain, beneath the cerebellum, consists largely of nerve fibers passing between the sensory apparatus and muscles of the body and the brain, and is termed the medulla oblongata.[1]

In the highest (bony) fishes the forebrain exhibits a further differentiation into two prominent ganglionic swellings on its floor, the corpora striata,[2] which are a further development of the olfactory system, and a thin mantle-like roof, the pallium,[3] which shows but little evidence of nervous structure. Slight grooves also appear on its surface, and a longitudinal furrow along the middle line on the dorsal side marks the beginning of the division of the cerebrum into two cerebral hemispheres. The amphibian brain also possesses this forebrain development, but the other parts of the brain are relatively simpler than in the fishes. In most fishes, all these parts lie in a straight line from before backward, but in a few the forebrain becomes bent ventrally on the midbrain, so that their long axes lie at a slight angle to one another; this condition persists throughout the series, and is so increased in man that the cerebrum lies at a right angle to the other parts of the brain.

The next distinct step above the fishes is seen in the reptiles; here the cerebrum, though smooth, is relatively larger than the other parts (as it so remains henceforth), and its two hemispheres are united by transverse fibers forming a distinct commissure.[4] The ganglionic masses forming the corpora striata encroach on the forebrain cavities, or ventricles;[5] and the olfactory fibers, which have

[1] Lat. *medulla oblongata*, oblong marrow.
[2] Lat. *corpus striatum*, streaked or striated body.
[3] Lat. *pallium*, mantle.
[4] Lat. *committere*, to unite.
[5] Lat. *ventriculus*, little belly.

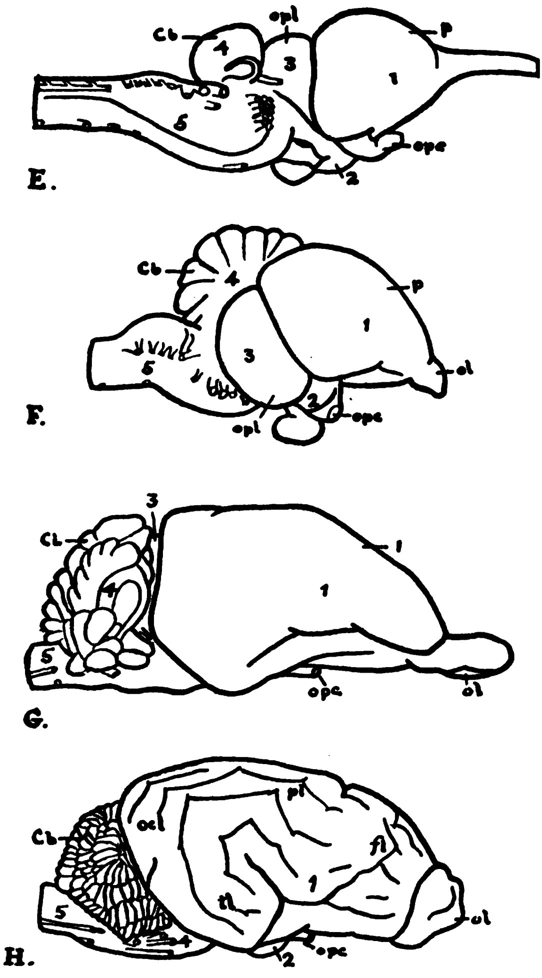


Fig. 2. — Wax Models of Vertebrate Brains

E. Alligator	1. Forebrain	cb, cerebellum	fl, frontal lobe
F. Pigeon	2. Interbrain	ol, olfactory lobe	pl, parietal lobe
G. Rabbit	3. Midbrain	opc, optic chiasm	ocl, occipital lobe
H. Dog	4. Hindbrain	opl, optic lobe	tl, temporal lobe
	5. Afterbrain	p, pallium	

previously ended in them, are now largely continued on to the pallium. The latter has become thickened, and, for the first time in the animal series, contains pyramidal-shaped cells, the characteristic nervous elements found in this portion of the system, which is henceforth known as the cerebral cortex.[1] Thus the pallium becomes the olfactory cortex, and, at various stages in the vertebrate scale, the fibers from other sense organs find endings here, forming higher centers for the remaining senses. The white interior of the cerebrum, the medulla,[2] lying immediately beneath the cortex, increases in size with the increase of the latter; it is composed of fibers from cell bodies in the ganglia beneath it and in the cortex above, which pass to and from the newly formed cortical centers. The cerebellum is found to be comparatively small, most reptiles being of sluggish disposition. Another distinct feature of the reptilian brain is the existence of the parietal[3] eye, and a process which connects it to the posterior roof of the forebrain. This eye (its structure indicates that it must be used for vision) is lost as we go up the series, but the forebrain extension, which forms a stalk for the eye, persists throughout the mammals as a vestigial, non-nervous structure, known as the pineal[4] body.

The brain of the bird is intermediate in character between those of the reptile and mammal, and has less resemblance to the former than might be expected from their similar ancestry. The basal ganglia (corpora striata) are here relatively larger than in any other group, the pallial cortex is better developed than in reptiles, and traces of other cortical centers than olfaction can be detected, the whole cerebrum being much larger and extending back to the cere-

[1] Lat. *cortex*, bark. [2] Lat. *medulla*, marrow.
[3] Lat. *paries*, a wall; the parietal bones form the side walls of the skull. [4] Lat. *pinus*, pine cone.

bellum, which is also relatively large and noticeably fissured. The optic lobes are prominent, but are pushed down on to the sides of the brain by the overlying cerebral hemispheres, on which frontal,[1] parietal, and temporal[2] regions can now be recognized.

In mammals, the brain reaches its greatest perfection, the increase in development being constant and complete from the lowest forms to man. The principal point in differentiation from the brain of the lower vertebrates is the increase in size and complexity of the pallium, or cerebral cortex, both absolutely and relatively to the other parts. Thus the cerebral hemispheres become larger and extend farther back over the underlying parts, as we ascend the series, until in mammals, of which the sheep may be taken as an example, they entirely overlie the midbrain, and in man, the cerebellum as well. The cortex is now in communication with all the sense organs of the body, and sends efferent fibers farther and farther back, overlying the earlier fiber systems of the brain stem and cord, and directly controlling the muscular apparatus. Not only does the cerebrum increase in size, but its surface becomes convoluted and fissured, so as to afford a considerable increase in its surface (cortex), without necessitating a corresponding general enlargement. These fissures and convolutions take on a more or less regular pattern in the higher mammals, those of the sheep being typical of the entire series; and this pattern holds for all these higher forms, though somewhat obscured in the primates (monkeys and man) by the addition of many connecting furrows between the primary fissures. Even in those mammals whose cerebral hemispheres remain smooth, the four general divisions into frontal, parietal, temporal, and occipital[3] lobes may be recognized.

[1] Lat. *frons*, front. [2] Lat. *tempora*, the temples.
[3] Lat. *ob*, against, and *caput*, head; the back of the head.

Another important feature of the mammalian brain is the great development of the commissures; of these the corpus callosum[1] and fornix[2] between the hemispheres, and the pons[3] connecting the two sides of the cerebellum around the ventral side of the medulla oblongata, are the most important. The olfactory lobes in the mammals diminish in relative size, and the cerebellum is relatively smaller than in the birds. The paired optic lobes, or corpora bigemina,[4] of the lower vertebrates, now become four in number, corpora quadrigemina,[4] lying in two pairs, one behind the other. The pineal apparatus lies buried beneath the overlying cerebrum, and has now become vestigial. The cavities of the original brain vesicles take on definite form, and constitute the system of ventricles; they become relatively smaller in the higher mammals, their walls being encroached upon by the nerve fibers which form the central portions of the brain, and which have vastly increased in number. They are also constricted by infoldings of the cerebral walls due to the deepening of external fissures, and by the prominence of isolated ganglionic masses of nerve cells, such as the corpus striatum, below the cortex. The corpus striatum does not attain the relative size in mammals that it does in birds, and is, moreover, broken up by the passage through it of a thick bundle of nerve fibers, the internal capsule. These fibers connect the nerve cells in the cortex with the muscles and sensory organs of the body, relaying (that is, forming a connection) with the processes of other neurones, whose cell bodies lie in the ganglia (*e.g.* the corpus striatum) at the base of the brain and in the spinal cord.

It is thus seen that the higher brain consists essentially of two elements of structure: centers containing cell bodies

[1] Lat. *corpus callosum*, hard body.

[2] Lat. *fornix*, arch.

[3] Lat. *pons*, bridge.

[4] Lat. *bi*, two, *quad*, four, and *geminus*, twin.

situated in the cortex of the cerebrum (and cerebellum), in the basal ganglia, and in the brain stem; and of conduction regions, made up of the fibers of these cells. The latter run across from one region of the brain to another, and into and out of the cerebrum, connecting it with other parts of the nervous system. Their richness largely depends on the number of nerve cells in the brain, which in turn is largely dependent on the development of the cortex, which we have seen regularly increases throughout the vertebrate series. As collections of nerve cells give a grayish appearance to the brain, and the fiber sheaths are white, it will be understood why the mammalian cerebrum is composed of a thin layer of gray matter on its surface and a white interior, in which are isolated masses of gray. It must be remembered that white matter always means nerve fibers, or areas of conduction for the nervous impulses, and that gray matter means connecting or relay stations for the fibers (which have lost their white sheaths), these relay stations also containing the nerve cells, which are largely concerned with the nutrition of the fibers.

Directions: If it is possible, brains of the eel, a bony fish, a frog, a bird, a rabbit, and a rat, cat, or dog, should be secured, and carefully examined and drawn. If it is not possible to obtain some or all of these, museum specimens or wax models may be used. The student should recognize on each of these the main divisions of the brain and the various external features mentioned in the text in the description of each type.

II

ONTOGENY

An examination of the development of the brain in the individual is highly essential for the beginner, there being no better method of acquiring an accurate conception of the intricate relations and functions of its various parts than by observing step by step the changes that mark its evolution from a simple tube to the highly specialized condition of the adult. The description given here has been largely taken from human embryology, but it is applicable in its early stages, at least, to the individual development of the brains of the vertebrates as a whole, and especially to that of the other mammals.

As early as the second week after the fertilization of the egg, while the ovum is but a hollow sac, the cells in the median line of the embryonic area on its surface become thickened and differentiated from the rest, forming the medullary plate. Soon the edges of this plate fold up over its grooved center; the groove deepens, the edges meet above it, and the primitive neural tube or canal is formed. The cells which take part in this process originate entirely from the ectoderm, the external of the three primary cell layers from which all parts of the body are formed. From this neural tube the entire nervous system arises, all true nervous tissue being, therefore, of ectodermal origin. The anterior portion of the neural tube, by a process of unequal growth in its different parts, and the folding of one part over the other, becomes the brain, the posterior portion, the spinal

cord. The cavity of the neural tube becomes the canal of the cord and the cavities (ventricles) of the brain, which are therefore continuous with each other.

Before the tube is entirely closed, two constrictions appear in its anterior part, dividing this region into three vesicles, which constitute the primary forebrain, midbrain, and hindbrain. [See Fig. *A*.] The forebrain and hindbrain again divide, the brain now being composed of five vesicles — from before backward, the secondary forebrain (prosencephalon),[1] the primary forebrain or interbrain (diencephalon),[2] the midbrain (mesencephalon),[3] the secondary hindbrain (epencephalon),[4] and the primary hindbrain or afterbrain (myelencephalon).[5] [See Figs. *B* and *C*.] From these five vesicles all parts of the brain distinctly originate, and these early divisions may still be detected in the adult condition, although with increasing difficulty, as we go up the vertebrate scale to man. Simultaneously with this division, three important bendings or flexures take place: the cephalic[6] flexure, by which the primary forebrain is bent ventrally on the midbrain, so that the roof of the midbrain projects dorsally; the pontal flexure, by which the area of the hindbrain corresponding to the future pons takes on a distinct ventral projection; and the nuchal[7] or cervical[8] flexure, by which the afterbrain is bent slightly forward on the spinal cord in the region of the neck. [See Figs. *D*–*F*.] These flexures are less marked in other mammals

[1] Gr. *pros*, before, and *enkephalos*, brain.

[2] Gr. *dia*, between, and *enkephalos*, brain.

[3] Gr. *mesos*, middle, and *enkephalos*, brain.

[4] Gr. *epi*, on, upon, and *enkephalos*, brain; from the position of the cerebellum.

[5] Gr. *myelos*, marrow, and *enkephalos*, brain; referring to the medulla oblongata.

[6] Gr. *kephalē*, head.

[7] Lat. *nucha*, nape of the neck.

[8] Lat. *cervix*, neck.

than in man, and in the latter only the cephalic retains its original flexion.

Two early and important changes take place in the primitive forebrain. The first is the outgrowth of the optic vesicles, one from either side, each becoming lengthened out into a slender stalk with a cup-shaped termination; the cup becomes the retina of the eye — the stalk, attached to the interbrain, the optic nerve. [See Figs. *B–D*.] The second change is the division into forebrain and interbrain. This occurs by the budding forward of the anterior wall of the primary forebrain, forming a diverticulum or secondary forebrain, which soon becomes divided by the formation of a median cleft into two lateral halves, the cerebral vesicles, whose development into the future cerebrum we must now trace, disregarding for the moment the interbrain. [See Figs. *B–E*.]

The cerebral vesicles enlarge to an unequal degree in the different species of vertebrates, being greatly in excess of the other regions of the brain in the mammals, and enormously so in man. By a multiplication of the cells which form their walls, they extend upward and backward over the interbrain and midbrain, and in man, over the hindbrain as well, until the great area of cerebrum has reached its adult condition, where it constitutes the most striking and characteristic feature of the nervous system of the higher vertebrates. During this process, the cells on the walls of these cerebral hemispheres assume the character and arrangement of neurones, the cell bodies remaining at the surface in the superficial gray matter, or cortex, of the cerebrum, while the axis cylinder processes (axones) [1] are directed inward from the surface, and form a large part of the area of white matter, or medulla. The first axones to appear in the medulla arise from nerve cells in the inter-

[1] Lat. *axis*, axis, or pole.

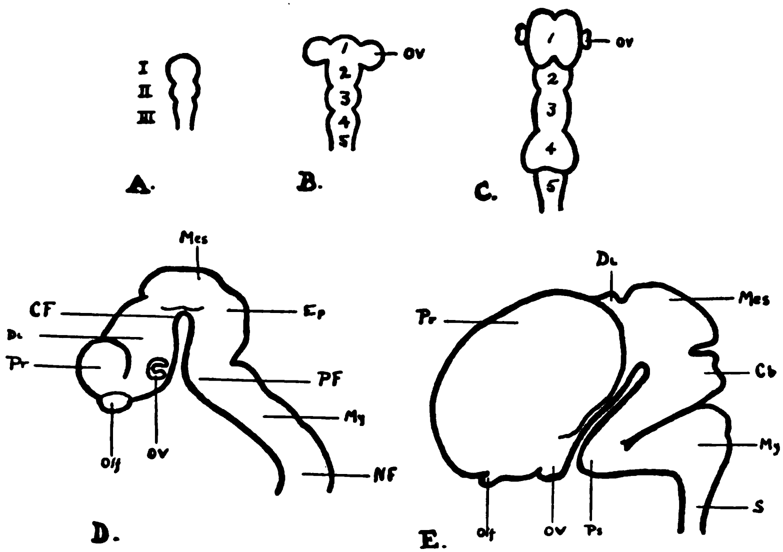


Fig. 3.—The Development of the Brain

(A), (B), (C) Successive steps in the formation of the primary vesicles
(D) Lateral view at three weeks
(E) Lateral view at seven weeks
I, II, III. Primary fore-, mid-, and hindbrains
1, 2, 3, 4, 5. Secondary forebrain, interbrain, midbrain, secondary hindbrain, and afterbrain

Cb, cerebellum
CF, cephalic flexure
Di, diencephalon
Ep, epencephalon
Mes, mesencephalon
My, myelencephalon
NF, nuchal flexure
Olf, olfactory vesicle
OV, optic vesicle
PF, pontal flexure
Pr, prosencephalon
Ps, pons
S, spinal cord

brain, and, passing into the hemispheres at the point where the latter overlie the interbrain, end in the cortex of the different sensory areas. Later, the fibers which arise in the cortex pass down through the interbrain, completing the union at this point between the two parts.

The original cavities of the cerebral vesicles have extended with them over the other brain regions, but are still connected with the other brain cavities by two openings, known as the foramina[1] of Monro, which constitute a Y-shaped passage. This passage unites the cavity of the interbrain below and behind with the anterior ends of the lateral ventricles, as the cavities of the two cerebral hemispheres are called. [See Figs. *F* and *L*.] The lateral ventricles become relatively smaller as the development of the brain proceeds, being encroached upon by the cerebral wall, especially the thickened portion on the floor of each hemisphere, the corpus striatum, and the thick fiber bundle passing through it and connecting the interbrain with the cortex, the internal capsule. Nevertheless, the ventricles form a hollow interior for the greater mass of each hemisphere, and are a constant and important constituent of the brain.

As the cells of the cortex develop much more rapidly than the underlying parts, the surface of the brain is thrown up into many convolutions, with intervening fissures. The more conspicuous divisions of the entire cortex are known as lobes, the less complete as gyri.[2] Some fissures are so deep as to produce a corresponding projection on the walls of the ventricles. These are known as total fissures, the most important of which are the fissure of Sylvius, the dentate, and the choroid fissures.

The fissure of Sylvius is formed by the cessation of growth of a spot on the lateral wall of the developing cerebral hemisphere, which, as it continues to expand, almost completely

[1] Lat. *forare*, to pierce. [2] Lat. *gyrus*, circle.

surrounds this area, forming the temporal lobe below, the parietal and occipital lobes above and behind, and the frontal lobe in front. [See Figs. *I* and *K*.] The depressed area thus produced becomes a fissure, pushing ahead of it an isolated mass of gray matter, the corpus striatum, which bulges into the fore and outer wall of the lateral ventricle. The cortex which is involved in this process of fissuration becomes depressed below the adjacent surface as the island of Reil, which in the human brain is completely hidden from view by the overlying convolutions. On the mesial surface of each cerebral hemisphere are early seen two parallel fissures, which arch upward from near the lower anterior end of the frontal lobe and downward behind along the mesial surface of the temporal lobe. The larger, more superficial, of these becomes the dentate [1] fissure, forming a prominence on the floor of that portion of the lateral ventricle which passes into the temporal lobe (the inferior horn of the lateral ventricle), the elevation being known as the hippocampus.[2] [See Fig. *G*.] The smaller of the two fissures, the choroid fissure, enters into the formation of the transverse fissure, which will be more fully described in the consideration of the interbrain.

Another important fissure in the human brain is the fissure of Rolando, on the external surface of each hemisphere; its analogue in the sheep is generally thought to be the cruciate fissure. [See Figs. *I* and *K*.] This does not reach its full development until much later than the other fissures; it effects the division between the frontal and the parietal lobes. The longitudinal fissure of the brain has already been seen, in its early condition, as the median cleft which forms the cerebral vesicles from the secondary forebrain

[1] Lat. *dens*, tooth; from the toothed appearance of the adjacent dentate gyrus.

[2] Gr. *hippos*, horse, and *kampos*, sea animal; sea horse.

vesicles. This deepens to completely separate the hemispheres, except at their lower anterior part, just in front of the foramina of Monro, where they still retain a slight attachment to the interbrain in the median line, known as the lamina terminalis [1] (the hemispheres also being attached to the interbrain by the extension between them of their fibrous systems).

It is not to be supposed, however, that the cerebral hemispheres are entirely separated from one another, for a third great factor in the development of the cerebrum here becomes manifest (the other two are the multiplication of neurones and the formation of folds), namely, the formation of adhesions between the opposed mesial surfaces of the two hemispheres. There results from this fusion a great band of white fibers passing from one side of the cerebrum to the other, the corpus callosum. It begins at the bases of the vesicles near their anterior ends, and extends upward and backward over the interbrain and midbrain. [See Figs. *F*, *G*, *H*, and *L*.] Beneath this and just behind the point where it first forms, other adhesions occur which give rise to the fornix. This consists of white fibers which lie transversely beneath the posterior portion of the corpus callosum, and which pass outward on either side into the temporal lobe; they form the lyre and body of the fornix. [See Figs. *G*. and *L*.] In addition to these, the fornix is made up of longitudinal fibers, which represent the lower mesial edges of the cerebral vesicles. These pass from the sides of the interbrain forward and upward in front of the foramina of Monro and then backward, in close apposition to the interbrain, becoming united in the middle line at the body of the fornix, and then separating to pass outward and downward along the floor of the inferior horn of the lateral ventricle to the tips of the temporal lobes. This portion

[1] Lat. *lamina*, plate, and Gr. *terma*, limit; the limiting wall.

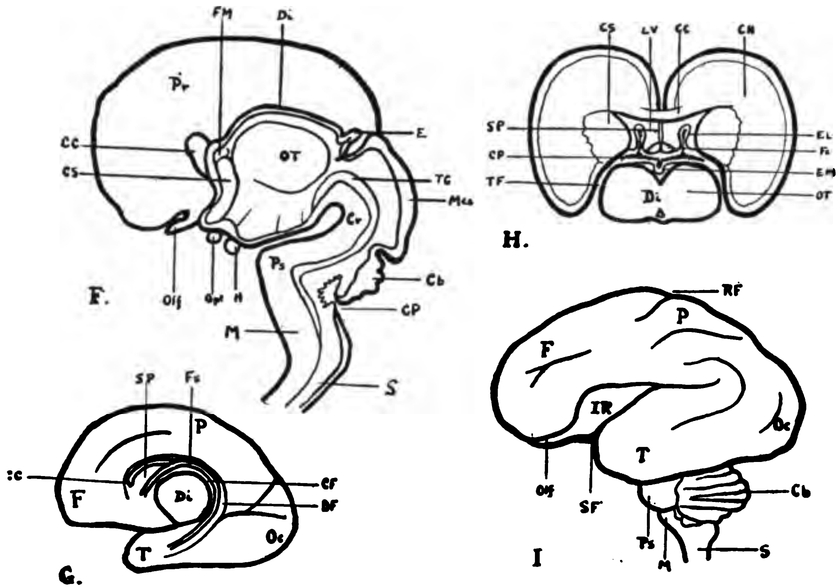


Fig. 4.—The Development of the Brain

(F) Sagittal section at three months
(G) Sagittal section at four months, brain stem removed
(H) Schematic cross section through the developing brain
(I) Lateral view at six months

Cb, cerebellum
CC, corpus callosum
CF, choroid fissure
CH, substance of cerebral hemisphere
CP, choroid plexus of fourth ventricle (posterior medullary velum)
Cr, crura
CS, corpus striatum
Di, diencephalon
DF, dentate fissure
E, epiphysis (pineal body)
F, frontal lobe
Fx, fornix
FM, foramen of Monro
H, hypophysis (pituitary body)
IR, island of Reil
LV, lateral ventricle
M, medulla oblongata
Mes, mesencephalon
Oc, occipital lobe
Olf, olfactory lobe
Opt, optic chiasm
OT, optic thalamus
P, parietal lobe
Pr, prosencephalon
Ps, pons
RF, Rolandic fissure
S, spinal cord
SF, Sylvian fissure
SP, septum pellucidum
T, temporal lobe
TG, tegmentum
TF, transverse fissure

of the fornix, called the fimbria,[1] is thus seen to almost completely surround the interbrain, and, with the hippocampal cortex, undoubtedly represents the greater part of the forebrain vesicles of more primitive brains (largely concerned with the sense of smell), which have been stretched out with the developing cerebral hemispheres.

The corpus callosum and the body of the fornix are in close apposition; anteriorly to the body they are, however, separate, and between the corpus callosum above and the fornix below is found an isolated portion of the longitudinal fissure, bounded on either side by the original walls of the cerebral vesicles. The walls do not, however, develop gray cortical matter as in other regions, but remain in a rudimentary condition, and are seen as two thin sheets of tissue in apposition, termed the septum pellucidum.[2] [See Figs. *G*, *H*, and *L*.] Between these two walls is the fifth ventricle, which is obviously not a true ventricle, as it does not communicate with the other brain cavities.

The olfactory lobes, so conspicuous in the sheep and many other vertebrates, are an outgrowth from the cerebral vesicles, their cavities communicating with the lateral ventricles. [See Figs. *D*, *E*, and *I*.] In man the cavity soon disappears and the lobe itself is found in a more or less atrophic condition, having become merely a bulb connected to a small area of cortex at the base of each hemisphere.

Returning now to the primary forebrain or interbrain, which was left in its early vesicular condition, it will be found to have produced its own characteristic structures simultaneously with the changes which have taken place in the secondary forebrain, although it has not reached the high degree of development of the latter. Its lateral walls become enormously thickened, and form two large ovoid

[1] Lat. *fimbria*, fringe.
[2] Lat. *septum*, wall, and *pellucere*, to shine through; transparent wall.

masses of gray matter with some intermingled fibers, the optic thalami.[1] [See Figs. *E–H*, and *L*.] From the optic thalami large bundles of fibers pass upward into the hemispheres, constituting a large part of the internal capsule. The floor of the interbrain becomes considerably diversified. The anterior part remains thin as the lamina cineria,[2] but posteriorly to this there is an outpocketing of the floor which forms a small tube, the infundibulum,[3] and behind this is another bulging, the tuber cinerium,[4] which eventually encircles the infundibulum. On the posterior end of the tuber cinerium two small elevations appear, the mammillary[5] bodies, which correspond to the point where the fibers of the anterior pillars of the fornix reach their downward limit and turn back upon themselves. The end of the infundibulum becomes the posterior lobe of the pituitary[6] body or hypophysis,[7] which is found connected by it to the mature brain. The anterior lobe of the pituitary body is formed from the primitive pharynx, by the extension upward of a pouch, which becomes cut off from the pharynx when the skull develops. Thus the pituitary body is evidently not a true part of the brain, and that small portion which arises from the infundibulum soon loses its resemblance to nerve tissue.

The roof of the interbrain remains extremely thin, except at its sides, where it forms the fibrous connection with the hemispheres above, and at its posterior part, where it becomes thickened and evaginated to form the pineal body (epiphysis).[8] This body is found in all vertebrates and represents in the higher animals the stalk of the rudimentary

[1] Gr. *thalamos*, bed; from its appearance on looking down into the lateral ventricle.
[2] Lat. *cineria*, ash-like.
[3] Lat. *infundibulum*, funnel.
[4] Lat. *tuber*, swelling.
[5] Lat. *mamma*, breast.
[6] Lat. *pituita*, phlegm.
[7] Gr. *hypo*, under, and *phyein*, to grow; the part growing under the brain.
[8] Gr. *epi*, on, and *phyein*, to grow; the part growing upon the brain.

eye found in the reptiles. The remainder of the roof of the interbrain forms an extremely thin sheet of tissue, to which its investing pia mater[1] and that covering the under side of the cerebral hemispheres, are adherent. The membrane thus formed by these three tissues is the velum interpositum[2] [superior choroidal tela[3]], and, stretching between the two optic thalami, it forms a roof for the cavity of the interbrain, the third ventricle.

It is at this point also that those blood vessels which, arising in the arterial circle at the base of the brain, make up the choroid[4] plexus, enter the lateral ventricles. As previously stated, the choroid fissure, which is found on the mesial surface of each cerebral hemisphere and extends down the mesial surface of the temporal lobe, is one of the total fissures of the brain. It does not, however, push solid brain matter before it as do the other brain fissures, for the infolded wall is here extremely thin, consisting of but a single layer of ependyma[5] (the thin epithelial lining of the ventricles). [See Fig. *H*.] The vessels of the choroid plexus, inclosed between the two pia matral layers of the velum interpositum, press in through the transverse fissure of the brain, as the space between the roof of the interbrain and the overlying cerebral hemispheres is called. Continuing, they enter the choroid fissure, which is thus seen to be but a lateral extension of the transverse fissure, and push the pia mater of the temporal lobe and the ependyma before them into the ventricle. The choroid plexus therefore appears to be within the lateral ventricles, whereas it is in reality contained in one of the total fissures and is shut out from the interior of the ventricle by the ependyma. These

[1] Lat. *pia mater*, tender mother.
[2] Lat. *velum*, veil, and *interpositum*, interposed.
[3] Lat. *tela*, web.
[4] Gr. *chorion*, a fetal membrane, and *eidos*, like.
[5] Gr. *ependyma*, an upper garment; the clothing of the ventricles.

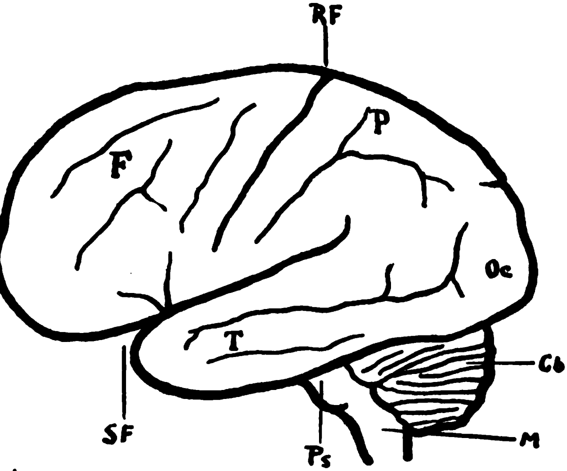
blood vessels contained in the velum interpositum also afford a choroid plexus for the third ventricle, by pushing inward the thin roof of the interbrain and the pia mater overlying it. They are therefore shut out from this ventricle, as they are from the lateral ventricles, by a single epithelial layer and a layer of pia mater. The choroid plexuses of these three ventricles meet anteriorly at the foramina of Monro, but are all formed by an invagination into these cavities of the velum interpositum and its vessels, via the transverse fissure.

The vesicle of the midbrain does not divide secondarily, but connects the interbrain in front with the hindbrain behind; its cavity, the aqueduct of Sylvius, therefore forms a passageway from the third ventricle to the fourth, the cavity of the hindbrain. The walls of the midbrain thicken ventrally to form the crura of the cerebrum, two large bundles of fibers, which are made up of axones of the cells of the cerebral cortex sending impulses down into the regions below the interbrain, and of axones from cells in these lower levels passing to the higher. [See Figs. *F* and *L*.] It is obvious that these fibers passing forward and upward from the midbrain and through the interbrain to the hemispheres form the principal connection between the latter and the remainder of the brain, the slender lamina terminalis being the only morphological union between these parts. The roof of the midbrain is thickened to form the corpora quadrigemina (bigemina in the birds), which comprise important lower centers for vision and hearing; they are covered over by the cerebellum behind and the cerebrum in front in the mammals, and by the cerebrum above in man.

Behind the midbrain the secondary hindbrain, or epencephalon (the anterior division of the primary hindbrain), develops into two important structures, the cerebellum and the pons Varolii. The latter, formed by a flexure and thick-

ening of the ventral wall, consists of a large bundle of transverse fibers which run upward on either side to the cerebellum. [See Figs. *E*, *F*, and *L*.] Through and beneath these transverse fibers run the great bundles which are a continuation of the crura of the midbrain above and the fiber tracts of the afterbrain and spinal cord behind. The cerebellum grows from the posterior part of the dorsal wall and becomes highly developed and specialized, its gross structure and inner development resembling not a little that of the cerebrum, as it is composed of a largely convoluted exterior of cortical gray matter and an internal white medullary portion. The anterior part of the dorsal wall remains thin and undeveloped as the anterior medullary velum; this is continuous with the corpora quadrigemina (the dorsal wall of the midbrain) anteriorly, and with the cerebellum behind. The lateral walls of the hindbrain form the connecting fibers from the pons below to the cerebellum above, the middle peduncles of the cerebellum; and from the cerebellum to the optic lobes in front, on either side of the velum, the superior peduncles of the cerebellum. The cavity of the hindbrain forms the anterior half of the fourth ventricle, the posterior half being formed by the cavity of the afterbrain.

The roof of the fourth ventricle is thus formed by the anterior medullary velum and cerebellum in front, and by a thin sheet of tissue behind, the posterior medullary velum, which constitutes the undeveloped dorsal wall of the afterbrain (myelencephalon), and is continuous with the cerebellum. The lateral walls of the afterbrain early become developed to form the inferior cerebellar peduncles, consisting of fibers which pass between the cerebellum and the myelencephalon (and spinal cord), on either side of this thin roof. The ventral wall of the myelencephalon becomes greatly thickened and forms the medulla oblongata, which



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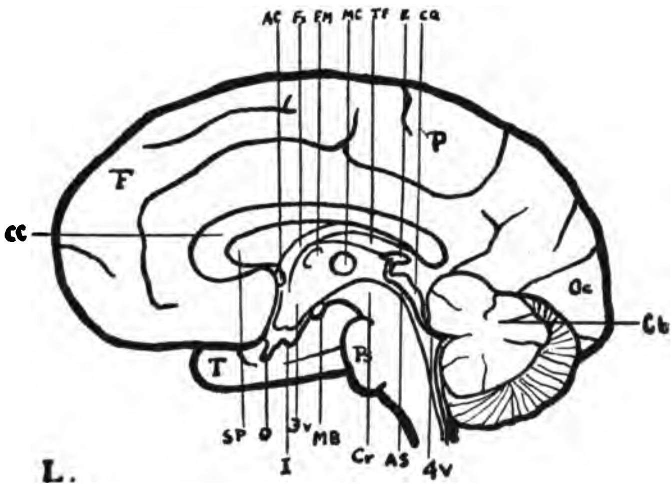

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Fig. 5.—The Adult Human Brain

(K) Lateral surface	(L) Sagittal section
AC, anterior commissure	MC, middle commissure
AS, aqueduct of Sylvius	O, optic chiasm and nerve
Cb, cerebellum	Oc, occipital lobe
CC, corpus callosum	P, parietal lobe
Cr, crura	Ps, pons
CQ, corpora quadrigemina	RF, Rolandic fissure
E, epiphysis	SF, Sylvian fissure
F, frontal lobe	SP, septum pellucidum
FM, foramen of Monro	T, temporal lobe
Fx, fornix	TF, transverse fissure
I, infundibulum	3 v, 3d ventricle
MB, mammillary bodies	4 v, 4th ventricle

consists for the greater part of nerve fibers passing between the spinal cord behind and the crura in front, with isolated masses of gray matter scattered through it. [See Figs. *F* and *L*.] The much greater development of the floor as compared with the roof of the afterbrain brings its cavity close to the dorsal surface, where it is flattened out in the shape of a triangle, which, meeting the similarly shaped cavity of the hindbrain, gives the fourth ventricle a rhomboidal contour. Its thin roof behind the cerebellum, with its investing layer of pia mater, is called the inferior choroidal tela, because, being pushed in by blood vessels from without, it forms the choroid plexus of the fourth ventricle. Like the choroid plexus of the lateral ventricle, this plexus invades the space of the cavity, but is really shut out from it by the thin layer of epithelium which it pushes before it.

To the student who has not yet studied the form-relations of the brain, many of the foregoing points will be obscure. For this reason he is urged to reread this chapter, and indeed, the preceding chapter also, after he has completed the dissection of the sheep's brain which follows. It is, nevertheless, essential that an outline of the ontogenetic development of the brain be given at this point, as it forms a basis for the study of many of the more complicated structures to follow (as the choroid plexus and hippocampus), which is indispensable to their proper understanding. The chapters on development should, therefore, be constantly referred to as the student proceeds, direct references being made to them in the succeeding chapters at the more important places.

DIRECTIONS: It will be found valuable for the student to carefully study and make drawings of several stages of the development of the brain of one of the higher mammals or man. If embryo sheep's brains cannot be obtained, those of the pig are usually available, and are to be preferred to museum specimens or models.

III

REMOVAL OF THE BRAIN

Its Membranes and Blood Supply

Of the several methods which have been suggested for the removal of the sheep's brain from the skull, the following has been found in the author's experience to be the most practicable, especially when the heads of full-grown sheep are used, in which the bone is exceptionally hard and thick.

Instruments: A sharp handsaw, a pair of heavy, and a pair of light, bone-forceps, heavy dissecting forceps, a sharp scalpel, and a pair of scissors.

Directions: Laying the head on one side, saw transversely across it on a line which runs from the ventral margin of the orbit to the ventral surface of the occipital condyle. Repeat this on the other side, entirely separating the lower portion, which includes a part of the nose and upper jaw and almost the whole of the lower jaw, from the upper portion, in which the cranium and brain are still intact. The dissection is now made from the exposed surface of the base of the cranium. Begin by carefully cleaning its entire base and sides of muscle and projecting pieces of bone, cutting away from their articulations the remaining fragments of lower jaw and completely cleaning out the orbit, being careful to distinguish and leave intact the optic nerve. With the bone clippers snip off close to their bases the occipital condyles (avoiding the projecting portion of the spinal cord), and all other free pieces of bone above the solid base.

Saw cuts are now made on the base as follows: two longitudinal (antero-posterior) cuts parallel to each other one half inch from either side of the middle line (so that they will pass through the center of the bases of the occipital condyles); three cuts across the other two at distances of one, two, and three inches from the posterior end of the base. Great care must be exercised that these saw-cuts do not penetrate through the bone

and so injure the underlying brain; they should be made deep enough, however, to enable the bone to be broken along the lines of the cuts. Now with the handle of the scalpel carefully separate the spinal cord with its thick covering of dura mater [1] from the bone surrounding it, for a distance inward of at least one inch. *This process of separating the brain with its dura mater from the bone by blunt dissection, before removing any piece of bone, constitutes the most essential point* in the removal of the soft, spongy brain from its hard, closely fitting case.

With the heavy bone-forceps pry off the most posterior piece of bone enclosed by the saw-cuts, inserting the lower blade of the forceps between the dura mater of the cord and the bone, and lifting the bone away from the cord. This process of separation of the dura mater and cutting and prying away, is repeated with the two remaining squares of bone, so that the ventral surface of the medulla oblongata, pons, and pituitary body are exposed, all invested by dura mater.

Begin now on the lateral surface of the cranium, pressing one blade of the forceps into the fissure at the base of the orbit, taking care to keep it posterior to the optic nerve, and cut a piece of bone out of this portion of the skull, exposing a portion of the temporal lobe of the brain. While this step may injure the dura at this point, it is more advisable than attempting to tear the bone away from the free edge already made, except in the soft skulls of young lambs. From the opening made on each side over the temporal lobes, the bone may be torn away in all directions, exposing the entire side and posterior base of the brain. *In every case first separate the dura from the bone, and then lift the bone away from the dura.* In this dissection, special care must be taken not to injure the dura covering the cerebellum, as this portion of the brain is very soft and easily injured in the fresh specimen.

When the bone has been removed on both sides to a line one-half inch below the dorsal surface of the brain,[2] the anterior portion of the base in the middle line must receive attention, as the bone is still intact here. With the lighter bone-forceps, tear away most of the spongy bone over the anterior end and then dissect out the optic chiasm, locating it by tracing up the optic nerves from their exposed position in the orbit. This should be done slowly and carefully, leaving the dura intact at all points. The overhanging piece of spongy bone, which now alone remains over the

[1] Lat. *dura mater*, hard mother.

[2] It must not be lost sight of that the skull with inclosed brain is resting on its dorsal surface, *i.e.* upside down, and that all parts are named in accordance with their normal relative position.

ventral surface, should be separated from the olfactory bulbs in contact with it. These bulbs are the softest portions of the brain and are adherent to the adjacent bone by means of the numerous small nerves they send off to pass into the spongy bone, thence into the cavities of the nose. Gently depressing the soft bulbs with the handle of the scalpel, snip off all the restraining fibrils between the bulbs and the bone with the scissors. When the bulbs are free on all sides, the bone-forceps may be carefully inserted and this piece of bone also removed. The brain is now in condition for removal.

With the scalpel handle peel the dura back from the top of the skull which now remains, insert two fingers under the anterior portion of the brain and, gently raising it from its bed in the skull, reach in with the scissors and cut the dura free, where it is adherent to the skull on each side. Here it forms the lateral boundary of the longitudinal or sagittal [1] sinus, a trough made by the dura and the skull, containing venous blood (*i.e.* blood returning from the brain to the heart). At a point near the cerebellum the scissors meet a firm sheet of dura passing transversely across the skull top. This is the tentorium [2] of the cerebellum, which separates the cerebellum from the cerebrum, but has a large opening on its ventral margin through which the brain stem passes from the cord and medulla behind to the cerebral hemispheres in front. Along its attachment to the skull, another trough-like sinus [3] is found, the transverse sinus; its junction with the longitudinal sinus is known as the confluens sinuum,[4] and at this point the dissection from the front must be abandoned, the brain dropped back into its place, and the tentorium approached from behind. The dura of the cord, medulla, and cerebellum is therefore carefully raised from the skull and with one finger under the cerebellum, and one under the cerebrum of the same side, the tentorium is snipped off with the scissors near its attachment to the skull. When this is repeated on the opposite side, the brain may be lifted out.

Holding it gently in the hollow of the hand, wash it in slowly running water, then lay it on its ventral surface on a bed of cotton and with the scissors cut what remains of the dura the entire length of the brain in the middle line, reflecting the two halves of the dura onto the ventral surface. Turning the brain onto its dorsal surface, again cut the dura longi-

[1] Lat. *sagitta*, arrow; straight through the brain from before backward.

[2] Lat. *tentorium*, tent; from the manner in which it stretches across the skull.

[3] Lat. *sinus*, a hollow.

[4] Lat. *confluens*, the place of flowing together (of the sinuses).

tudinally along its middle line as far forward as the pituitary body. Lifting up each lateral edge, cut away from the dura the cranial nerves that are seen to leave the cord, medulla, pons, and crura, and enter the dura, making this cut in each case as close to the dura as possible. *Under no circumstances exert any traction upon the nerves,* lest they be broken off short, for the investment of dura which each nerve receives is closely adherent and cannot be pulled off. The dura cannot be removed from the pituitary body or the optic chiasm, and so must be clipped off close to their margins.

The brain is now ready for preservation, as it is covered only by its thin, closely investing membrane, the pia mater, in which run the blood vessels supplying the exterior with nutrition, and by a third, ill-defined membrane, the arachnoid,[1] which intervenes between the dura and pia, and contains beneath it the cerebro-spinal fluid, which surrounds the brain and spinal cord, and occupies their interior. These cannot be safely removed until the brain is well hardened, as their removal now would lacerate the cerebral substance. That the brain may retain its original shape both inside and out, its ventricles should be injected with the fluid in which it is to be preserved. If the pituitary body is to be retained, make a small slit in the anterior side of the little stem upon which it rests (the infundibulum); or, if it is removed, a hole is seen in the end of the infundibulum, where the pituitary body has been cut away. Into this hole inject with a piston syringe and fine cannula the preserving fluid, ten per cent formaline, until it is seen to emerge from under the temporal lobe. If the brain does not swell up during this operation, the cannula has not been properly placed and the operation should be repeated. It is best during this operation to hold the brain under the surface of the fluid with just the infundibulum emerging. Wrap the brain in a layer of cotton and rest it gently in the preserving jar; it should have its position frequently changed and the injections of the ventricles may well be repeated during the first few days. After a week in the ten per cent solution, an equal amount of water should be added, and in this five per cent solution the brain should remain until used.

The human brain is invested similarly to the sheep's by the dura and pia mater, and the tentorium is similarly placed, though in this case its position is horizontal rather than vertical as it runs across the cavity of the skull, owing

[1] Gr. *arachnē*, a spider's web.

to the fact that the cerebellum is underneath, rather than behind, the cerebrum. In addition, the human brain possesses a firm sickle-shaped fold of dura, the falx,[1] which passes down into the great longitudinal fissure between the two cerebral hemispheres and runs its entire length, uniting with the tentorium behind and below. In its upper border is found a venous sinus which corresponds with that of the sheep, here called the superior longitudinal [sagittal] sinus, as distinguished from another sinus found in its lower free margin, the inferior longitudinal [sagittal] sinus. At the confluens sinuum both of these meet the transverse or lateral sinus, which carries the outgoing blood from the brain to the large veins at the base of the skull.

A word should be added concerning the blood supply to the brain through its arterial system. In this regard the brains of the sheep and man are essentially alike and the general description given here will apply to both. Large arteries from the neck (and the spinal cord) unite at the base of the brain to form a complete arterial circle surrounding the pituitary body and the optic chiasm — the circle of Willis. From this, arteries pass upward over the surfaces of the cerebrum in the principal fissures, being closely adherent to the pia mater, in which they are contained. They supply the exterior and the greater part of the interior of the cerebral hemispheres, dipping into the cerebral substance from all parts of the surface. The remainder of the cerebrum receives nutrition from short arteries which enter the base of the brain directly from the arterial circle, and from other small arteries which pass upward through the transverse fissure of the brain and its ventricles, supplying its interior as the choroid plexus, elsewhere described. The cerebellum and brain stem are supplied by branches from the arterial circle and spinal

[1] Lat. *falx*, a sickle.

D

arteries, which are distributed over their surfaces and enter their substance from all sides. The venous system of the interior of the brain will be considered in a later chapter. While the method of entering the skull from its base will have destroyed all the arteries external to the dura mater, the circle of Willis will be found intact beneath the dura, and this and the general distribution of arteries adherent to the pia should be closely examined, so that a general understanding of the blood supply and the investing membranes of the brain may be obtained at this stage of its dissection.

IV

DORSAL AND LATERAL SURFACES

The brain of the sheep is particularly adaptable for elementary study because it is easily obtainable in the fresh state; it is practically identical in structure with the brain of other higher mammals, and is for this reason best suited as an introduction to the more intricate, but essentially similar, brain of man. In size and form it ranks near the upper end of the vertebrate series, and presents for examination all the important constituents of the central organ of the nervous system in its highest development.

At first glance (see Directions *A* at the end of the chapter), the brain as a whole will be seen to consist of three parts. The large part occupying the anterior three-quarters is the cerebrum, consisting of two great hemispheres, separated on their dorsal side by a deep longitudinal fissure, and arising, as we have seen, from the primary forebrain. Behind this is another prominent body, rounded and freely fissured, the cerebellum, a development of the primary hindbrain. Beneath these two, occupying the posterior half of the ventral surface, the brain stem, from the primary midbrain and hindbrain, extends posteriorly into the spinal cord. This stem is largely composed of white matter concerned in the conduction of nervous impulses to and from the gray matter of the parts above; it is the exterior of this gray matter which forms the surface of the cerebrum and cerebellum, *i.e.* the brain cortex [substantia corticalis]. This cortex is seen to be thrown up into well-marked folds or

convolutions, separated by grooves or fissures; the locations of those appearing on the dorsal and lateral surfaces will now be considered.

The main divisions of the cerebrum are known as lobes, the main dividing grooves as fissures; smaller convolutions and furrows are called gyri and sulci[1] respectively. The degree of convolution varies greatly among the different mammals and no entirely satisfactory explanation has been given for this variation, though as a rule higher and larger animals show greater convolution than lower and smaller ones. Evidently the arrangement of the folds depends upon two factors: the amount of development of the pallium, or cortex, peculiar to the species, as has been already noted, and the size of the skull cavity, which depends on other conditions than cerebral extension. Moreover, the fissuration of the most highly convoluted brains, as that of man, is not entirely a further development of the pattern of an upper mammalian brain, as that of the sheep, for each possesses definite fissures to which there is nothing analogous in the other. Nevertheless the brain of the sheep exhibits the typical fissuration of the mammalian brain, and is sufficiently similar to the human brain in this regard to prepare the student for the complexities of the latter. There are, also, three main types of fissures to be detected throughout the mammalian series: sagittal fissures, parallel to the long axis of the brain; arcuate[2] fissures, which arch upward over a vertical fissure on the middle of each side of the cerebrum (the fissure of Sylvius); and coronal[3] fissures of a vertical, ascending type.

On the dorsal aspect of the sheep's brain two prominent fissures stand out in the form of a cross. One of these is the longitudinal fissure, which runs from one end of the

[1] Lat. *sulcus*, furrow.
[2] Lat. *arcus*, a bow.
[3] Lat. *corona*, a crown; as a crown would set on the head.

cerebrum to the other, separating it into two cerebral hemispheres. At the anterior and posterior ends it completely separates the hemispheres; in its central portion it is terminated ventrally by a great band of fibers, which passes between them, the corpus callosum. This fissure, is the median cleft which originally divided the secondary fore-brain into the two cerebral vesicles, and is therefore constant in all but the lowest vertebrates. The second fissure, which crosses the longitudinal, is known as the cruciate.[1] This is seen to run transversely from the longitudinal fissure outward and slightly forward on each side, at about the junction of the anterior with the middle third of the cerebrum; it extends to the lateral border. The prominence and extent of this fissure varies greatly in different mammals; it is fairly constant in the higher forms, and is thought to be analogous to the fissure of Rolando [central sulcus] in man.

On the lateral aspect, there are also two prominent fissures. The first of these is called the rhinal[2] fissure and extends horizontally on the line where the lateral and ventral surfaces meet, from the anterior end of the cerebrum to very near its posterior end. It separates the cerebrum proper above, from the olfactory bulb (or lobe), the olfactory root, and the hippocampal gyrus below (named from before backward), which constitute the olfactory apparatus proper. This fissure attains greater prominence in lower mammals in which the olfactory development is relatively great, but in man, who exhibits but the atrophied remnants of this apparatus, no such structure exists. At about the center of this fissure another passes vertically upward on the side of the cerebrum, at right angles to the first. This is the fissure of Sylvius [lateral fissure of the cerebrum], a very constant and important fissure throughout the series. In man this fissure is almost horizontal and extends back-

[1] Lat. *crux*, cross.

[2] Gr. *rhis*, nose.

ward, giving off an anterior and an ascending limb. The vertical fissure of the sheep sends off a long anterior and a short posterior ramus,[1] the former extending forward nearly to the anterior tip of the brain, parallel to and just above the rhinal fissure. The main fissure however extends upward onto the dorsal surface, where it ends just above and behind the lateral extremity of the cruciate fissure.

Arching over the upper extremity of the Sylvian fissure is the series of arcuate sulci, four in number. In ruminants, such as the sheep, only those nearest the fissure extend forward far enough to become arched around it, as those near the longitudinal fissure are shorter and are more parallel to the latter. In most mammals, however, all these sulci are similar to the outermost here, and in man slightly similar fissures are found. They may be named the first, second, third, and fourth arcuate sulci, as they approach the mesial line. Another constant sulcus in the sheep, and in some other mammals, is the superior frontal sulcus, running directly forward from about the center of the cruciate sulcus to near the tip of the cerebrum, where it ends in a bifurcation. There are numerous other sulci to be seen on the surface of the sheep's brain, but they are neither constant in position for that animal nor homologous to any similar sulci in other species, and so they will not be considered further.

Having examined the fissures, it will now be possible to locate the lobes and gyri which they more or less completely mark off. There are five lobes to be seen on the external surface — the frontal, parietal, occipital, temporal, and olfactory — the completeness of their separation varying among the different animals. In the sheep that portion of the hemisphere anterior to the cruciate fissure may be termed the frontal lobe; it is seen to be relatively small,

[1] Lat. *ramus*, branch.

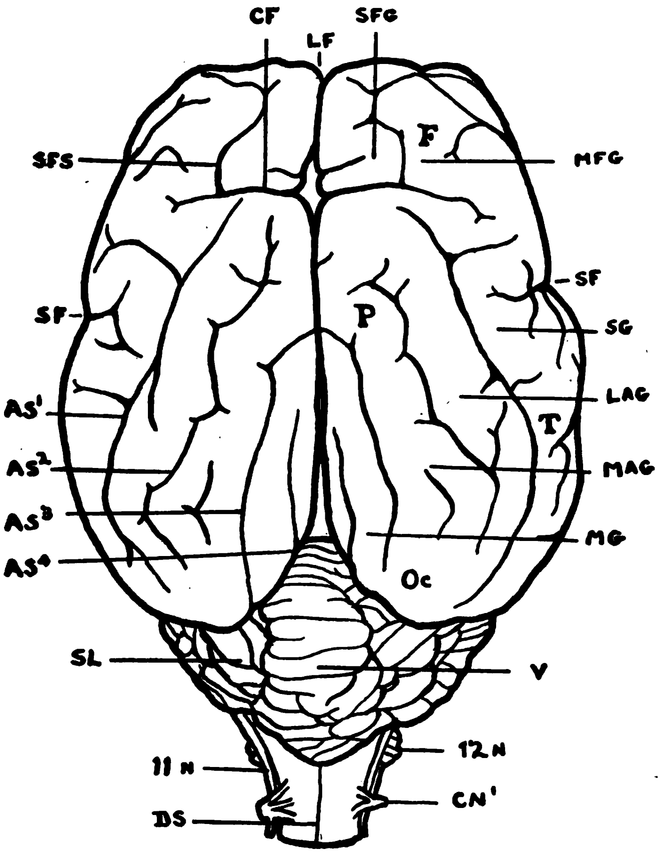


FIG. 6.—DORSAL SURFACE

AS[1], [2], [3], [4], arcuate sulci
CF, cruciate fissure
CN[1], 1st spinal nerve
DS, dorsal sulcus
F, frontal lobe
LAG, lateral arcuate gyrus
LF, longitudinal fissure
MAG, medial arcuate gyrus
MFG, middle frontal gyrus
MG, marginal gyrus
Oc, occipital lobe
P, parietal lobe
SF, Sylvian fissure
SFG, superior frontal gyrus
SFS, superior frontal sulcus
SG, suprasylvian gyrus
SL, superior lobe
T, temporal lobe
V, vermis
11 n, 11th cranial nerve
12 n, 12th cranial nerve

as it is in all mammals below man, the apes showing an intermediate form. In man, however, it attains an enormous size, almost equaling that of the remainder of the cerebrum, and forces both the Rolandic and Sylvian fissures backward, so that the latter extends more horizontally than vertically, and the former somewhat so. In man its cortex has been held by some to be concerned in the highest mental processes and to form the seat of those intellectual functions by which he is distinguished from the beasts, the difference in development of the frontal lobes somewhat supporting this view. It is at least certain that the frontal lobes, especially the left, are concerned in learning new acts, and in the operation of skilled acts and other educated movements. An area for the motor processes of speech has been definitely localized in the inferior lateral region of the left frontal lobe (seldom the right), and a center for writing slightly above it. It is probable that the smaller frontal lobes in the mammals below man are closely associated with their deficiency in these and other educated motor faculties.

Behind the cruciate fissure is the parietal lobe, occupying about one-half of the remaining dorsal surface and extending laterally to the posterior ramus of the Sylvian fissure. In some mammals (the simians) it is definitely marked off from the occipital lobe which lies behind it; but in man the division is not apparent on the external surface. In the latter, the parietal is separated from the frontal lobe by the fissure of Rolando, on the anterior side of which (that is, in the cortex of the frontal lobe) is the general motor area, and posterior to it the general sensory area (in the parietal cortex). The motor area of the human cortex runs the length of the Rolandic fissure, occupying a gyrus of the frontal lobe (the precentral or anterior central gyrus) which is parallel and just anterior to it. This area is the origin of the great pyramidal tract, which carries voluntary motor

impulses to the muscles, via the spinal cord. The general sensory area occupies a similar gyrus just behind the fissure (the postcentral or posterior central gyrus), and is the receiving station for impulses of sensation from the skin and body. Considering the cruciate fissure analogous to the Rolandic, it is probable that these relations hold in a general way for the sheep, as its motor area has been demonstrated in the frontal cortex, anterior to the cruciate fissure (although motor areas have been found posterior to this fissure in some mammals, as the dog). The occipital lobe, which occupies the posterior end of each hemisphere, is concerned with vision, the visual cortex in man being principally on the mesial surface of the lobe, surrounding the calcarine [1] fissure (which has no analogue in the sheep). The temporal lobe is that portion of the sheep's cerebrum lying ventrally to the parietal and occipital lobes, where the cortex is seen to project downward and slightly forward as a rounded elevation, the division being about on a line with the posterior ramus of the fissure of Sylvius. In man this lobe contains the higher center for hearing on the upper part (superior gyrus) of its external surface, the main center for smell at its tip, and possibly a center for taste.

The olfactory lobe is the bulb-like projection seen on the under side of the anterior end of each hemisphere, and is connected to the tip of the temporal lobe by the long olfactory root lying below the rhinal fissure. On its under side are numerous small nerves which convey impulses upward from the nose; it is therefore a lower center or relay for the sense of smell, the higher centers being in the cerebrum proper. In most of the vertebrates below the primates this sense (and corresponding apparatus) is very highly developed, the entire forebrain and later the entire cortex

[1] Lat. *calcar*, a spur; from the prominence this fissure makes on the interior of the human brain.

being concerned in its reception, as has been stated in Chapter I. In such animals as the sheep these parts are still in a highly organized condition, although other centers have been added to the cortex. In man, however, the apparatus is much smaller, the sense poorly developed, and the higher centers relatively restricted.

The lobes of the brain are subdivided by fissures into numerous convoluted folds or gyri, very few of which are constant throughout the mammalian series. Many gyri are, in fact, inconstant in any one species, and to this the sheep is no exception. The superior frontal sulcus divides the dorsal surface of the frontal lobe into two well-defined gyri; that nearest the longitudinal fissure is the superior frontal gyrus and that laterally the median frontal gyrus. The cortex of the former constitutes the motor area in the sheep, and therefore is not strictly analagous to the same gyrus in man, which is for the most part anterior to the motor area. At the junction of the dorsal and lateral surfaces, one or more sulci separate the superior from the inferior frontal gyrus, which is limited posteriorly by the Sylvian fissure and below by its anterior ramus. Beneath this, between the anterior ramus and the rhinal fissure is the orbital [1] gyrus, which at its posterior end is sunken below the surrounding surface of the cerebrum. This depressed portion constitutes the island of Reil (insula), which in man is so overhung by the adjacent folds of the frontal and temporal lobes (the operculum)[2] as to be completely hidden from the exterior.

The arcuate sulci divide the parietal and occipital lobes into a series of gyri, of which that arching around the Sylvian fissure lateral to the first arcuate sulcus may be called the supra-sylvian [angular]; that between the first and second

[1] Lat. *orbis*, a ring or circle; named from the bony orbit around the eye.
[2] Lat. *operculum*, lid.

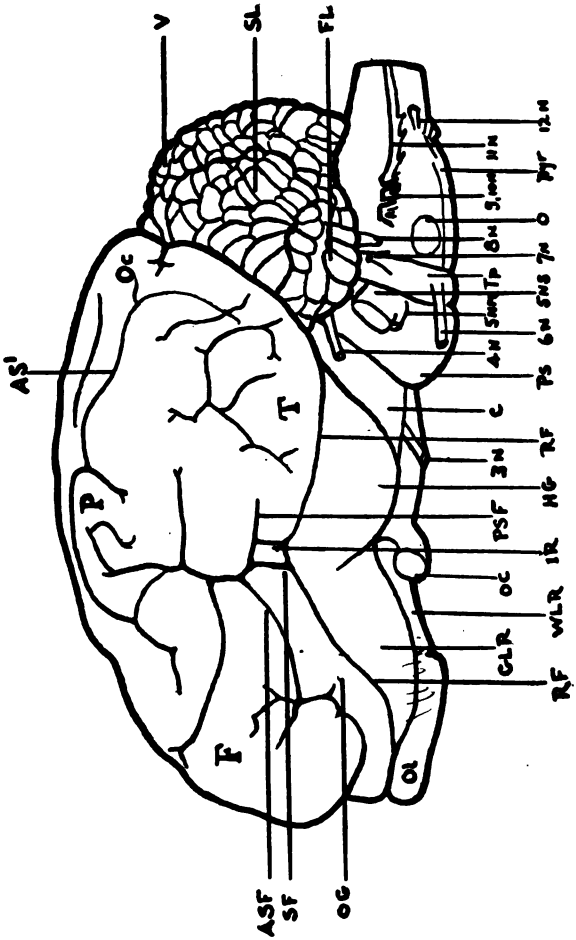


FIG. 7.—LATERAL SURFACE

AS¹, 1st arcuate sulcus
ASF, anterior ramus of Sylvian fissure
C, crus
F, frontal lobe
FL, flocculus
GLR, gray matter of lateral olfactory root
HG, hippocampal gyrus
IR, island of Reil
M, medulla oblongata
O, olive
Oc, occipital lobe
OC, optic chiasm
OG, orbital gyrus
Ol, olfactory lobe
P, parietal lobe
Ps, pons
PSF, posterior ramus of Sylvian fissure
Pyr, pyramid
RF, rhinal fissure
SL, superior lobe
SF, Sylvian fissure
T, temporal lobe
Tp, trapesoid body
V, vermis
WLR, white matter of lateral olfactory root
3, 4, 7–12 n; 3d, 4th, 7th–12th cranial nerves
5 NM, 5 NS; motor and sensory divisions of 5th cranial nerve

arcuate, the lateral arcuate gyrus; between the second and third, the median arcuate gyrus; and between the third and the longitudinal fissure, the marginal [supra-marginal] gyrus, having the fourth arcuate sulcus on its surface. The posterior end of the rhinal fissure separates the upper portion of the temporal lobe from its smooth rounded termination; the latter is continuous anteriorly with the olfactory root and is known as the hippocampal convolution or gyrus. The constant gyri of the human brain are much more numerous than those of the sheep owing to the greater size and richer convolution of the former; and as the only gyri of the sheep's brain which may be said to be analogous are the orbital gyrus, the island of Reil, and possibly the frontal gyri, the convolutions of the human cerebral cortex will not be further considered.

The cerebellum of the sheep is situated just behind the cerebrum, the anterior portion of the former being in close apposition to the posterior end of the latter. The one, developed from the hindbrain, and the other from the forebrain, together completely conceal the parts developed from the midbrain lying between them. In man the cerebellum, though absolutely larger, is relatively smaller than that of the sheep, due largely to the enormous development of the cerebral hemispheres; it lies moreover beneath, rather than behind, the cerebrum, owing to the permanent flexures of the original brain tube, mentioned in Chapter II. On examination, the cerebellum is seen to be characterized by two sets of fissures; the larger, few in number, run in a longitudinal direction, while numerous smaller fissures pass transversely across the convolutions so formed. It is important to name only the most prominent of these lobes, as there is no clearly defined differentiation of function between the parts of the cerebellum. The nerve paths entering and

leaving the cerebellum have been traced to different regions of its interior, but, as far as is known, the organ acts as a whole to coördinate bodily movements and maintain muscle tone and equilibrium.

The cerebellum is composed, like the cerebrum, of an outer layer of gray matter, or cortex, formed by myriads of neurones and short fibers, the long fiber processes or axones making up a large part of the white matter, or medullary core. The prominent lobe which runs around the median portion in a longitudinal direction is the vermis[1]; it makes almost a complete circle around the cerebellum, the part seen on the dorsal side being called the superior vermis, while that underneath forms the inferior vermis. The small convolutions, or folia,[2] on the dorsal surface of the vermis are usually irregular and coiled upon themselves, there being no regular arrangement. On either side of the vermis, there are about three well-marked sets of parallel lobes, which follow the course of the vermis in passing around under the cerebellum, and which become smaller laterally. These together may be termed the lateral lobes of the cerebellum, and in man attain a relatively large size. That portion of each lobe which overhangs the sides of the brain stem, constituting the most lateral folia of the cerebellum, is called the flocculus[3] throughout the mammalian series. Names are given to many portions of the human cerebellum to which nothing corresponds in the sheep, and in fact there is less external resemblance between these portions of the brains of the two species than between any other parts. In man only the vermis retains the worm-like appearance of the whole cerebellum of the sheep, the lateral lobes being flat and smooth, with only transverse fissuration.

The principal structures of the brain stem which appear

[1] Lat. *vermis*, worm. [2] Lat. *folium*, leaf.
[3] Lat. *flocculus*, a little tuft of wool.

on the lateral aspect of the sheep's brain, will be briefly named here and more fully dealt with in the next chapter. Just below the hippocampal gyrus two large white nerves form a cross, the optic chiasm.[1] Behind the hippocampal gyrus the brain stem extends backward as the crura,[2] enlarges beneath the cerebellum to form the pons and trapezoid[3] body, and posterior to them forms the medulla oblongata, which at the posterior end of the cerebellum narrows into the spinal cord. From the entire length of the brain stem the cranial nerves arise; the third from beneath the crura, the fourth and fifth from above the pons, the sixth below, and the seventh and eighth above the trapezoid body, the ninth, tenth, and twelfth from the sides of the medulla, while the eleventh extends forward along the sides of the cord to reach a position just posterior to the tenth.

DIRECTIONS: *A*. Carefully strip the blood vessels from the entire surface of the brain without injury to the cerebral substance. The arachnoid membrane will be removed with the vessels, but some of the pia will unavoidably be left behind. Locate on your specimen the various structures as they are mentioned in the text and learn their positions.

B. Make drawings of the dorsal and lateral aspects of your specimen, labeling all the parts you recognize.

[1] Gr. *chiozein*, to make a cross (X).
[2] Lat. *crus*, leg.
[3] Gr. *trapeza*, table; trapezoid, table-shaped.

V

VENTRAL SURFACE

THERE are many structures on the ventral surface of the sheep's brain which require careful study, as a majority of them perform important functions and almost all have a corresponding position in man. This aspect presents on either side the ventral portion of the lateral cortex, already considered, and just mesial to this the entire external portion of the olfactory system, separated from the former by the rhinal fissure. The anterior end of the longitudinal fissure, which here completely separates the cerebral hemispheres, is to be seen in the middle line; on either side of it is the ventral surface of the hemispheres, which may be considered to extend laterally to the rhinal fissure. The central portion of the posterior half of the ventral surface is, however, occupied by the brain stem, which thus covers up the parts above it. The most lateral portion of the cerebellum (the flocculus), may be seen on each side of the medulla oblongata.

From the posterior end of the two olfactory lobes, which were sufficiently treated in the preceding chapter, the olfactory roots extend backward; two of them may be seen behind each lobe. The lateral root [lateral olfactory stria [1]] is the larger of the two, running backward and outward to the hippocampal gyrus, with which it is directly connected. It is composed of gray matter laterally, and white matter mesially, and may be readily seen. The mesial

[1] Lat. *stria*, streak or line.

root [medial olfactory stria] runs backward and inward to the longitudinal fissure. It is smaller than the lateral root, but is readily found. It extends into the interior of the frontal lobes on their mesial surfaces, thus directly connecting the olfactory lobes with this portion of the cortex. The third, or internal, root [intermedial olfactory stria] lies between the other two; it runs directly into the brain substance and so cannot be seen except in dissection. Extending backward, each internal root becomes connected with its fellow by a transverse band, the anterior commissure, which will be studied later.

The olfactory lobe rests in a depression in the base of the frontal lobe, the olfactory sulcus; in the human brain this is but a narrow furrow, but has the same name and position. The convolution between each olfactory sulcus and the longitudinal fissure is the rectal [1] gyrus; it extends forward onto the anterior portion of the frontal lobe, having an analogous position in man. The area behind this, bounded laterally by the olfactory tract, and mesially by the longitudinal fissure, is called the anterior perforated space [anterior perforated substance], because of the perforations in its surface due to the entrance of numerous small arteries into the cerebral substance. Its gray matter forms a part of the olfactory cortex, and it is present, though smaller, in man.

The prominent bundle of fibers which form a white cross at the posterior limit of the longitudinal fissure is the optic chiasm or commissure. It is formed by the optic nerves, which, arising in the retina of the eye, and passing upward, backward, and inward, meet at the base of the brain, where their fibers separate, the lateral half of each continuing on the same side, the mesial half of each crossing to the opposite side, thus forming the chiasm. Beyond the chiasm, these fibers become the optic tracts, which pass upward on each side of the brain stem beneath the hippocampal gyrus and

[1] Lat. *rectus*, straight.

terminate in the optic thalami [thalami], developed from the walls of the early interbrain. Posterior to the chiasm there is found in most specimens (if removed as directed) a large ovoid body, the hypophysis. This has been sufficiently considered in Chapter II. Connecting it with the part above is a slender stalk composed of gray matter and blood vessels, the infundibulum; if this is opened it is seen to be hollow, communicating above with the cavity of the interbrain, the third ventricle. The infundibulum projects from a triangular eminence of gray matter, the tuber cinerium, which at its narrower posterior end terminates in a pair of rounded bodies, the mammillary bodies (sometimes only one is seen). These parts form the floor of the interbrain, which is continued forward and upward in front of the optic chiasm as a narrow wall, the lamina terminalis, the morphological connection with the forebrain.

On either side of the tuber cinerium is an extremely large bundle of white fibers, the two converging posteriorly. These are the crura [peduncles[1]] of the cerebrum, and are made up of almost all the nerve fibers which pass between the basal ganglia and the cortex (*i.e.* the higher brain centers), and the lower centers in the brain stem, cerebellum, and spinal cord. They form, then, the essential part of that portion of the brain stem which is the direct continuation of the fibers of the cerebral hemispheres, and are derived from the primary midbrain, of which they form the floor. Between them is a narrow cleft, the posterior perforated space [posterior perforated substance] of the same nature as the anterior perforated space, but relatively smaller than that found in man.

Beneath the cerebellum is a large bundle of fibers arching around the strands of the crura, the pons. Its transversely disposed fibers pass upward on either side into the white matter of the cerebellum, forming the middle peduncles

[1] Lat. *pedunculus*, little foot.

of the cerebellum [brachia [1] pontis]. The crural fibers are thus surrounded at this point by the pons beneath and the cerebellum above, although some of the fibers pass between and interlace with the transverse pontal fibers. On either side of the middle line, an elevation extends backward from the posterior border of the pons, indicating the position of the fibers from the motor area of the cortex, which, having passed through the crura, have emerged from under the pontal arch. From the resemblance of each to a pyramid (especially in man) they give their name to the whole system — the pyramidal tract. A transverse band of fibers, called the trapezoid body, is seen to run outward from the lateral margin of each pyramid just behind the pons; this probably corresponds to the same structure in man, which is not visible externally, and is made up of fibers arising at the entrance of the eighth (auditory) nerve, which, passing across to the opposite side, form a portion of the path from the ear to the cortex.

The club-shaped enlargement between the trapezoid body and the spinal cord is the medulla oblongata, forming the floor of the afterbrain; the pyramids make up its extreme ventral part. Other tracts of fibers make more or less noticeable elevations on the ventral surface of the medulla; there are also two sunken masses of gray matter known as the olives, which produce a prominence on either side of the pyramids just behind the trapezoid body. Throughout the length of the pons, trapezoid body, and medulla, a ventral sulcus runs in the middle line. It is to be noted that the brain stem is essentially made up of nerve fibers, although there are many isolated nuclei of gray matter scattered throughout the interior; the appearance of this portion of the brain is therefore white, while the cerebrum and cerebellum are gray, as only their cortices are visible.

[1] Lat. *brachium*, arm.

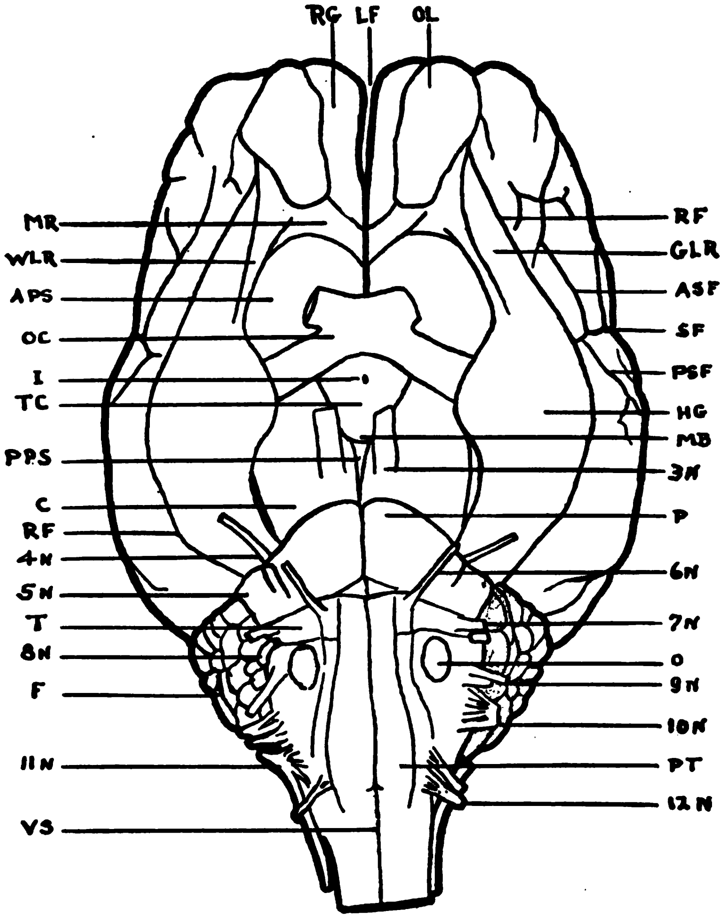


FIG. 8.—VENTRAL SURFACE

APS, anterior perforated space
ASF, anterior ramus of Sylvian fissure
C, crus
F, flocculus
GLR, gray portion of lateral olfactory root
HG, hippocampal gyrus
I, ~~island of Reil~~ ?
LF, longitudinal fissure
MB, mammillary bodies
MR, mesial olfactory root
O, olive
OC, optic chiasm
OL, olfactory lobe
P, pons
PPS, posterior perforated space
PSF, posterior ramus of Sylvian fissure
PT, pyramidal tract
RF, rhinal fissure
RG, rectal gyrus
SF, Sylvian fissure
T, trapezoid body
TC, tuber cinerum
TF, transverse fissure
WLR, white matter of lateral olfactory root
VS, ventral sulcus
3–12 n, 3d–12th cranial nerves

As the superficial origins of all the cranial nerves (*i.e.* their points of emergence from the brain surface) are to be seen on the ventral surface of the brain, it will be well to describe them here. These nerves are found in twelve pairs, and have either sensory or motor functions, or both. They supply the head (just as the spinal nerves supply the body), entering the brain from the sense organs and skin of the face, *i.e.* sensory to the head, or leaving the brain to supply the muscles of the head, *i.e.* motor. The deep origins of these nerves, as the nuclei of the nerve cells from which they arise are called, will be traced later; but it is to be noted here that the fibers of all the cranial nerves, or fibers of neurones which make relays with them, originally begin or eventually terminate in the gray matter of the cerebral cortex.

The first and second nerves are the olfactory and optic, respectively, and have been already examined. The third or oculomotor [1] nerves are of good size and leave the inner borders of the crura laterally to the posterior perforated space; they are motor and supply all but two of the muscles which move the eyeball. The fourth, or trochlear,[2] is a small nerve arising on each side of the dorsal surface of the hindbrain and is seen winding downward and forward in the space in front of the pons, between the crura mesially and the under surface of the cerebellum laterally. It is a motor nerve, controlling the superior oblique muscle of each eye. The large flat nerve extending forward from each lateral border of the pons is the fifth, or trigeminal,[3] nerve. This nerve is mixed, *i.e.* it possesses both a motor and sen-

[1] Lat. *oculus*, eye, and *movere*, to move.

[2] Gr. *trochilia*, a pulley (the muscle moved by this nerve works through a pulley).

[3] Lat. *tri*, three, and *geminus*, twin (there are three divisions to the nerve).

sory part. The former is much the smaller of the two and may be readily seen as the most ventral or mesial portion of the bundle; this supplies the muscles of mastication, while the larger portion is sensory, arising from the skin of the face.

The sixth, or abducens,[1] is a small nerve arising from the mesial end of the trapezoid body at each border of the pyramidal tract; its function is motor, passing to the external rectus muscle of each eye. In a lateral position to this, the seventh or facial nerve, motor to all the facial muscles but those supplied by the fifth, extends outward from the trapezoid body. Just posterior to the seventh, the eighth or auditory [acoustic] nerve is seen to arch downward from above. The superficial origin of the eighth is on the dorso-lateral surface of the medulla oblongata, hidden beneath the cerebellum; it is sensory from the ear, being the nerve of hearing and equilibrium.

In a groove along the external lateral border of the medulla a series of nerve filaments are given off which become grouped into one or more nerve bundles, which later separate out into two distinct nerves, the ninth or glossopharyngeal,[2] and the tenth, or vagus.[3] The first of these has its superficial origin in the groove just lateral to the olive, and is a sensory nerve from the back of the mouth and pharynx, being also the nerve of taste for the posterior third of the tongue. The vagus, whose filaments arise posteriorly to those of the ninth, is both motor and sensory, and has a very large and complex distribution, to the heart, lungs, and entire respiratory system, and to all the abdominal organs except those in the pelvis. On the same line with

[1] Lat. *ab*, away, and *ducere*, to lead (the eye is moved outward by the external rectus muscle).

[2] Gr. *glōssa*, tongue, and *pharynx*, pharynx.

[3] Lat. *vagere*, to wander; from its large distribution.

these two nerves, but behind them, the eleventh or spinal accessory is seen running forward along the sides of the cord and medulla oblongata, receiving filaments from both, and finally leaving in company with the ninth and tenth. The eleventh nerves are motor, supplying in man two prominent muscles on each side of the neck. The twelfth pair of nerves, the hypoglossal,[1] arise in the ventral surface of the medulla oblongata, at the posterior end of the lateral border of each pyramid; they are motor nerves, innervating the muscles of the tongue.

The medulla oblongata must be considered as two essentially distinct mechanisms: one, a transmission system for impulses passing between the higher centers and the spinal cord; the other, the seat of local reflexes furnished by the afferent and efferent connections between the medulla itself and the body. The nuclei and fibers concerned in the local mechanisms are to be found, in general, near the center of the brain stem, and are overlaid by the fibers from more distant parts, which are of later evolution. The fundamental nervous mechanisms of the lower vertebrates are therefore partially represented in the higher by the scattered masses of gray matter deeply laid throughout the medulla oblongata, which still retain functions of vital significance. Containing the local reflex centers for the cranial nerves, the medulla must be, from its connections through the tenth nerve, the center of control for respiration, the beat of the heart, the size of the blood vessels, and for many less vital reflexes. That connections of ever-increasing complexity are made between the fundamental and later developing systems, does not interfere with this conception that the medulla oblongata is composed primarily of these two mechanisms, a conception which the student will find very useful in gain-

[1] Gr. *hypo*, under, and *glōssa*, tongue.

ing an understanding of this complicated portion of the brain.

Directions: Examine and draw the ventral surface of the sheep's brain. Compare the exterior (dorsal, lateral, and ventral surfaces) of the sheep's brain with a model of the human brain (or the exterior of a preserved human brain, if possible), noting the similarities and differences of general shape, fissuration, and the position and development of all parts mentioned in the text. This comparison to the human brain model should be made at every stage in the dissection of the brain of the sheep.

VI

SAGITTAL SECTION

By making a mesial longitudinal section of the sheep's brain (see directions), a greater part of the remaining surface of the cerebral hemispheres, and many structures which furnish an important clue to the anatomy of the interior of the brain, are exposed. This sagittal or mesial aspect presents, in addition to the corresponding surface of the hemispheres, a median section through all the great commissures, as the corpus callosum and the fornix, and the smaller commissures, as the anterior and posterior; it lays bare the cavities of the interbrain, midbrain, hindbrain, and afterbrain, displaying the structures which compose their walls, and its sections the cerebellum in such a manner as to show the relation of its white and gray matter to good advantage.

It is questionable whether the gyri to be seen on the mesial surface of the hemispheres are at all analogous to those of man. Moreover, the nomenclature of these gyri in man is somewhat complicated, and the transposition of these names to any of the mammals is arbitrary. This surface in the sheep exhibits, however, at least one constant sulcus, which lies between and parallel to its dorsal edge and the corpus callosum, the large white fibrous mass lying ventrally. This sulcus may be called the sulcus cinguli[1] or the calloso-marginal sulcus, and the gyrus between it and the corpus callosum, the gyrus cinguli. This gyrus runs

[1] Lat. *cingulum*, girdle.

around the anterior end of the corpus callosum, and then ventrally, where it may be seen to be joined by the mesial root of the olfactory lobes, being known as the sub-callosal gyrus at this point. Posteriorly, it runs backward and downward around the posterior end of the corpus callosum, thence downward on the mesial surface of the temporal lobe, to join the hippocampal gyrus, as may be seen by lifting the temporal lobe away from the brain stem. (This portion of the hemispheres will be more carefully examined in a later dissection.) The gyrus cinguli and hippocampal gyrus thus form an almost continuous ring around the corpus callosum and upper brain stem, and these gyri, with the remainder of the olfactory apparatus, form what is known as the fornicate [1] or limbic [2] lobe.

Above the sulcus cinguli, the mesial surface may be considered as one gyrus, though broken up by several fairly constant sulci. This we will call the marginal gyrus, and its parts comprise the mesial surface of the various external lobes which have already been studied. In man, there are more or less definite sulci on this surface, which indicate the divisions between the lobes on the external surface (especially between the parietal and occipital), but in the sheep no analogous parts are indicated. Sometimes an intermediate gyrus may be detected between the callosal and marginal, and a very constant sulcus, the splenial,[3] is seen to separate it posteriorly from the marginal gyrus above it. These latter structures have no significance other than that attached to the main lobes of which they are a part. The gyrus cinguli and hippocampal gyrus, however, complete the circle of the limbic lobe, which is

[1] Lat. *fornicatus*, arched (*fornix*, arch).
[2] Lat. *limbus*, border.
[3] Gr. *splēnion*, bandage; the splenium of the corpus callosum, from which this is named, has this appearance.

formed in addition by the mesial root of the olfactory lobe, the subcallosal gyrus, and the lateral root of the olfactory lobe, and are therefore considered an essential part of the olfactory apparatus. Certainly, in the lower animals, whose olfactory systems make up almost the entire fore-brain, these parts seem to form an important cortical area for smell; in the poorly developed human apparatus, it is questionable whether the gyrus cinguli, at least, is still retained for this function.

Those connections of the olfactory system which have been worked out are very complicated, and have no place in an elementary treatise. It is, however, necessary to consider in addition to the limbic lobe those portions which make up such important structures as the fornix and anterior commissure. The former is the prominent white sickle-shaped band, seen in the mesial aspect, lying under the posterior end of the corpus callosum, and arching forward and downward to be lost near the base of the brain, behind the optic chiasm. It is composed of transverse fibers at its posterior part, running from one hippocampal gyrus up along the floor of the cavity of the temporal lobe, and then across the middle line to the hippocampus of the opposite side; this portion of the fornix is known as the lyre[1] [commissure of the hippocampus], and is seen here in cross section. The remainder of the fornix forms its pillars and consists of longitudinal strands, called the fimbriæ [fimbriæ of the hippocampus], which run upward from each temporal lobe in a manner similar to the fibers of the lyre, but on reaching the median plane turn forward and arch downward, into the sides of the interbrain. Here they reach their ventral termination in the mammillary body of each side, where the fibers turn and pass upward into the optic thalami, and thence the fibers relay onward in the brain

[1] Lat. *lyra*, lyre.

stem. (The optic thalamus is seen on the mesial section as a large rounded grayish mass just dorsal to the mammillary body.) Those fibers of the fornix in the temporal lobe are called the posterior pillars [crura] of the fornix, those passing into the interbrain its anterior pillars [columns of the fornix], and the portion in the median plane between these is known as the body of the fornix.

At a point in the anterior pillars, just in front of the optic thalami, is a round white spot, representing the transversely cut fibers of the anterior commissure. We have seen that this is formed by the internal roots of the olfactory lobes on each side, the two roots and the commissure forming a horseshoe-shaped bundle of white fibers. In the sheep very few connections are made by the anterior commissure other than this. In man, however, the greater part of these fibers extends backward and outward on either side, and then down through the temporal lobes to the hippocampal lobe, thus forming a commissure very similar to the lyre; whether this commissure is entirely of olfactory function is questionable. It is evident from the foregoing that the olfactory system is of relatively great importance in the sheep, and of even greater importance in lower animals, as the reptiles, and that for them consciousness must be largely confined to a world of smell.

The corpus callosum, the great band of fibers passing across the middle line between the two hemispheres, has already been noted on this section, cut transversely. The posterior club-shaped end is called its splenium; anteriorly, it bends sharply downward as the genu,[1] and ends in a short posterior extension, the rostrum,[2] the tip of which closely approaches the anterior surface of the fornix. Its fibers spread out laterally in all directions to the cortex of each hemisphere, as will be noted in a subsequent dissection.

[1] Lat. *genu*, knee. [2] Lat. *rostrum*, beak.

Between the anterior half of the corpus callosum above and the pillars of the fornix behind and below, is a triangular space filled in by a double layer of thin membrane. This membrane is the septum pellucidum, and the cavity between its two layers the fifth ventricle [cavity of the septum pellucidum], as explained in Chapter II. On either side of the septum pellucidum is a part of the cavity of each cerebral hemisphere, the lateral ventricle, which may be seen by cutting through the septum. A reference in Chapter II (the student should constantly refer to the first two chapters during his dissection), will make plainer the morphology of the structures so far considered in the present chapter, which have all arisen from the secondary forebrain or prosencephalon.

Just below the rostrum and the fornix, the lower anterior wall of the interbrain, the lamina terminalis, is seen; its significance has been previously considered. Below it, the median section of the optic chiasm appears; from this the optic tract runs upward and backward on the outer side of the brain stem to end in the optic thalamus. The median section of the latter has already been noted in this brain section, forming the lateral wall of the cavity of the interbrain, the third ventricle. The optic thalami will be seen again later, but it will be well to note that they are formed of gray matter, *i.e.* of the cell bodies and connecting fibers of neurones which furnish important relays for the incoming fibers of the optic tracts and for the general sensory (and other) fibers entering through the brain stem on their way to the cortex. The large central portion of the thalamus is seen to have been cut in making this section. This is the middle or gray commissure [intermediate mass], a point where the thalami on either side meet in the median plane; it is not, therefore, a true commissure, as this term is applied more properly to fibers passing across the middle line.

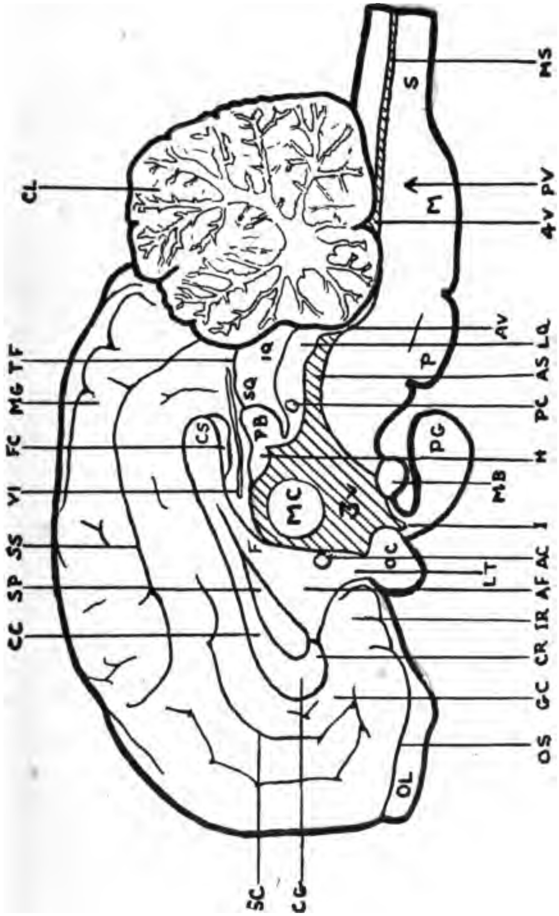


Fig. 9.—Sagittal Section

AC, anterior commissure
AF, anterior pillars of the fornix
AV, anterior medullary velum
CC, corpus callosum
CG, genu of corpus callosum
CL, cerebellum
CR, rostrum of corpus callosum
CS, splenium of corpus callosum
F, fornix
FC, fasciola cineria
GC, gyrus cinguli
H, habenulæ
I, insula
IQ, inferior corpora quadrigemina
IR, internal root of olfactory lobe
LQ, lamina quadrigemina
LT, lamina terminalis
M, medulla oblongata
MB, mammillary bodies
MC, middle commissure
MG, marginal gyrus
MS, spinal canal
OC, optic chiasm
OL, olfactory lobe
OS, olfactory sulcus
P, pons
PB, pineal body
PC, posterior commissure
PG, pituitary gland
PV, posterior medullary velum
S, spinal cord
SC, sulcus cinguli
SP, septum pellucidum
SQ, superior corpora quadrigemina
SS, splenial sulcus
TF, transverse fissure
VI, velum interpositum
3 v, 4 v, 3d and 4th ventricles (shaded)

The third ventricle is a narrow cavity compressed into a flat ring by the encroaching thalami and gray commissure. It communicates with the lateral ventricles of the hemispheres by the opening on either side, and just behind, the most anterior part of the body of the fornix, and above the anterior commissure, called the foramina of Monro [interventricular foramen]. It also extends downward into the infundibulum, which may be seen on the ventral border between the optic chiasm and the mammillary body, connecting with the large gray pituitary body below the latter. Above the ventricle and behind the thalamus is the vestigial pineal body, to which run anteriorly the habenulæ,[1] containing fibers concerned in the olfactory mechanism. The pineal lamina forms the remainder of the roof of the interbrain, which is continuous with the roof of the midbrain behind it. Between the splenium of the corpus callosum above, and the roof of the midbrain below, the velum interpositum [choroidal tela of the third ventricle] described in Chapter II, ~~is seen to enter~~; extending forward, it pushes downward into the third ventricle the thin anterior portion of its roof, furnishing the ventricle with the choroid plexus.

The parts of the midbrain are less numerous and complicated than those of the two anterior brain areas. The roof of this division is seen to consist of thick plates, the lamina quadrigemina, so called because of the superimposed optic lobes, or corpora quadrigemina. These are four rounded elevations placed in two pairs, superior and inferior (superior and inferior colliculi), the superior being much the larger; a superior and inferior lobe of one side are therefore to be seen in the present section. While they are known as the optic lobes, only the superior pair is concerned with vision, constituting one of the lower centers for this sense, while the inferior pair forms a lower center

[1] Lat. *habena*, rein.

for hearing. On the anterior end of the lamina quadrigemina, a round white spot indicates the transversely cut fibers of the posterior commissure of the brain. This commissure presumably connects the two optic thalami together, *i.e.* it is a commissure of the interbrain, and it also contains fibers which cross to the thalamus of one side as a continuation of longitudinally disposed fibers in the dorsal part of the floor of the midbrain behind, these fibers probably carrying sensory impulses upward.

The floor of the midbrain is made up of the crura, two great nerve bundles of the anterior brain stem. They are seen in this section cut longitudinally; anteriorly, their fibers run outward, forward, and upward, to the sides of the interbrain (thalami) and the hemispheres; posteriorly they are connected with the fibers of the medulla oblongata. The cavity of the midbrain is a narrow passageway, the aqueduct of Sylvius [aqueduct], connecting the third ventricle in front with the cavity of the hindbrain, the fourth ventricle, behind.

The remaining parts to be seen on the mesial surface of the brain are derived from the two divisions of the primary hindbrain, *i.e.* the secondary hindbrain and the afterbrain. From the former are to be observed the large cerebellum above and the pons below; the latter is composed mainly of the medulla oblongata. This section of the cerebellum displays the arrangement of its white and gray matter, the gray cortical portion, containing nerve cells, occupying the exterior and dipping inward between the tree-like prolongations of the white interior, composed of medullated nerve fibers. To this appearance of the white matter the older anatomists gave the name of arbor vitæ.[1] The white matter reaches the surface of the cerebellum for the most part at the sides of its ventral surface and therefore appears

[1] Lat. *arbor vitæ*, tree of life.

to be entirely internal in the median section. This fibrous interior is a direct continuation of the three peduncles of the cerebellum on each side, one pair of which, the middle, were seen on the ventral and lateral surfaces of the brain. These run downward around the brain stem, to become continuous with the pons, which is to be seen here in cross section as a large white oval body on the ventral surface of the section, directly under the cerebellum. The pons forms the floor of the hindbrain, and through it and just above it the longitudinal fibers pass between the crura and the medulla oblongata.

The cavity of the hindbrain enlarges as it passes backward to form the anterior half of the fourth ventricle. The posterior half of the ventricle is similarly formed by the anterior enlargement of the cavity of the afterbrain. In addition to the cerebellum, the roof of the hindbrain is made up anteriorly of a thin sheet, the anterior medullary velum, or the valve of Vieussens, which connects the cerebellum and the corpora quadrigemina, or roof of the midbrain, in the middle line. Behind the cerebellum is another similar membrane, the posterior medullary velum, which is the anterior part of the roof of the afterbrain, and connects the afterbrain to the cerebellum. Thus the cerebellum with the anterior medullary velum forms the anterior portion, and the posterior medullary velum, the posterior portion, of the roof of the fourth ventricle, while its floor and sides are made up by the floor and sides of the hind and afterbrains, as was described in Chapter II. The pia mater over the posterior medullary velum and the velum are pushed inward by blood vessels, forming a choroid plexus for the fourth ventricle.

The floor of the afterbrain is much thicker than its roof and forms an essential portion of the brain stem, the medulla oblongata. This region is composed both of fibers

passing between the spinal cord and the crura, and of areas of gray matter or nuclei which form important relays for the fibers of the many cranial nerves which it gives off, and for fibers passing to and from the cord, as explained in Chapter V. The posterior portion of the afterbrain cavity is narrower than the anterior and forms the central canal of the medulla oblongata, being continuous with the central canal of the spinal cord, the medulla merging into the cord posteriorly.

Directions: With a long thin-bladed knife, cut the brain into two lateral halves by passing it into the longitudinal fissure, after separating the hemispheres with the fingers, and making one sweeping downward cut in an absolutely vertical direction. If the two sagittal portions are found to be slightly unequal, choose the larger for the present chapter, trimming it down on its mesial face until the exact middle line is reached. Examine and draw as in the previous sections.

VII

THE CORPUS CALLOSUM AND THE LATERAL VENTRICLE

HAVING followed the directions (*A*) at the end of the chapter, the student may now turn to the study of the structures he has exposed. The first sweep of the knife has sectioned the cerebrum horizontally, displaying the arrangement of its white and gray matter. The cortex is seen to occupy the extreme edge of the section, dipping in with the sulci, thus greatly increasing its area without correspondingly increasing the total size of the hemispheres. In the sheep's brain the cortex is about one eighth of an inch thick. It is composed, as has been said, of the cell bodies and short connecting processes of multitudes of neurones, whose long fibers or axones, together with the axones from other cells, make up the great white interior of each hemisphere. This internal or medullary portion, cut across as it is in the present section, is designated the centrum semiovale.[1] It represents the cut fibers of cells lying in the cortex about it, or in the nuclei and ganglia at a lower level, *i.e.* fibers passing out of or into the cortex — the cerebral projection fibers — and fibers passing between two different areas of the cortex either on the same or opposite sides of the brain — the cerebral association and commissural fibers, respectively. After the examination of this area, recourse should be again made to the directions for dissection (*B*), and the next lower level exposed.

The corpus callosum is the great commissure of nerve

[1] Lat. *centrum semiovale*, semioval center.

fibers passing transversely across the brain, connecting the two cerebral hemispheres. Most of the commissures so far examined have been concerned with olfaction; the corpus callosum, however, is concerned in associating those portions of the cortices of the two hemispheres which make up the areas participating in other functions. The development of the corpus callosum is, therefore, commensurate with that of the cerebral cortex; for we have found that the small cerebrum of the lower vertebrates is principally concerned with the reception of smell, and that the expansion of this area goes hand in hand with the acquirement of higher centers for the remaining senses. In man, therefore, the corpus callosum is larger than in any other mammal, corresponding to the vastly greater area of cerebral cortex which he possesses.

pari passu

The division of the corpus callosum into rostrum, genu, body, and splenium has been seen in its longitudinal section in the previous chapter. In tearing away the overlying gyri, it has no doubt been also observed that the fibers of the corpus callosum spread out in various directions from the middle line — upward, downward, forward, and backward, but in all cases, outward as well. These radiations of fibers cannot, naturally, be adequately shown in any one dissection, as the majority must be torn away or ripped across to display the course of a few. It can be readily understood, however, that the fibers of the corpus callosum connect all portions of the cortices of the various lobes and gyri of one cerebral hemisphere with those of the other. As the strands pass from the genu outward and forward into the frontal lobes, they form, by their shape, what is termed the forceps anterior or minor[1] [frontal part of the corpus callosum], and a similar radiation backward into the occipital lobe is known as the forceps posterior, or

[1] Lat. *forceps minor*, lesser tongs.

major[1] [occipital part of the corpus callosum]. As they pass laterally, many will be seen to dip downward and forward, entering the temporal lobe. Here they form the roof of the inferior horn of the lateral ventricle (that portion of the lateral ventricle which constitutes the cavity of the temporal lobe), although a thin layer of association fibers running between the frontal and occipital lobes on each side separates them from the ventricle proper, the whole forming a roof called the tapetum.[2] As they pass outward, also, they are somewhat separated by the passage between them of the fibers passing upward and downward from the cortex, the projection fibers, and the association fibers connecting various areas of the cortex of the same hemisphere.

While most of the fibers of the corpus callosum are transverse, there are four very small strands on the dorsal surface which run longitudinally. The two farthest from the middle are known as the lateral longitudinal striæ, and those near the middle line are the median longitudinal striæ; together they constitute the striæ of Lancisi. They are undoubtedly atrophied gray matter and connect the dentate gyrus [dentate fascia] and faciola cineria[3] at the posterior end of the corpus callosum, with the subcallosal gyrus under its anterior end. They represent some of the early olfactory tracts and gyri vestigial in the higher mammals. Another similar bundle which may be mentioned in this connection is the cingulum, a narrow but well-defined band of fibers just overlying the corpus callosum but contained in the substance of the gyrus cinguli; it runs upward and backward around the corpus callosum from the anterior perforated space to the temporal lobe, giving off fibers to the

[1] Lat. forceps major, greater tongs.
[2] Gr. *tapēs*, a mat.
[3] Lat. *fasciola cineria*, ash-like little bandage.

cortex of the gyrus cinguli. It may be considered an association tract of the olfactory system and an intimate portion of the limbic lobe.

The corpus callosum having been removed from one side as directed (*C*), the lateral ventricle is exposed to view. The two lateral ventricles are, as we have seen many times, the cavities of the cerebral hemispheres, communicating with the third ventricle, and so with the whole ventricular system, by the foramina of Monro. Each cavity is long and narrow and in man consists of a body [central part] and three horns, the anterior horn projecting forward and downward into the frontal lobe, the posterior straight backward into the occipital lobe, while the inferior curves outward and downward into the temporal lobe. There is no posterior horn in the sheep, the body of the ventricle continuing directly into the inferior horn; the anterior horn, on the other hand, is prolonged forward into the olfactory lobe.

The roof of the lateral ventricle is formed by the fibers of the corpus callosum and the tapetum; mesially, it is bounded by the body of the fornix and the corpus callosum, with the septum pellucidum between them; laterally, by the corpus striatum, the large basal ganglion with intervening fibrous strands located at this point in each hemisphere; anteriorly, by the genu of the corpus callosum; posteriorly, by the junction of the hippocampus with the posterior fibers of the corpus callosum and with the medullary interior of the occipital lobe. The parts which make up the floor of the ventricle are, from before backward: the caudate nucleus[1] (a part of the corpus striatum), the choroid plexus of the ventricle (with the optic thalamus beneath it), the fimbria, and the hippocampus. These are seen in the present dissection and should be located now.

[1] Lat. *cauda*, tail, and *nux*, a nut.

The entire interior is lined with a thin epithelial membrane derived from the original nervous substance, the ependyma, which in fact forms a continuous lining for all the cavities of the brain.

The roof, the anterior, and the mesial walls of the lateral ventricle have already been examined. The most anterior structure found on its floor is the caudate nucleus, a great nuclear mass which, with a similar body, the lenticular[1] nucleus [lentiform nucleus], and a great bundle of projection fibers passing between them, the internal capsule, makes up the corpus striatum. The latter is formed (as was observed in Chapter II) by a thickening of the floor of the early cerebral vesicle; it is one of the most important of the basal ganglia or primary centers, and its cell bodies form an important relay station for the fibers which pass through it on their way to or from the cerebral cortex. Only the caudate nucleus is seen on the floor and sides of the lateral ventricle, the internal capsule lying laterally and posteriorly to it, while the lenticular nucleus is ventral to the capsule. In man the caudate nucleus may be seen posteriorly as a long slender tail-like process arching backward over the lateral border of the optic thalamus and around its posterior end to its under surface; in the sheep the optic thalamus is not visible in the floor of the ventricle, being concealed by the choroid plexus, but the tail of the caudate nucleus, while not as long as in man, has the same relation to it. In the furrow between the caudate nucleus and the thalamus, which cannot be seen until the fringe of choroid plexus is removed, is a slender band of white fibers, the stria terminalis,[2] which arises in the head of the nucleus and runs alongside it to the extremity of its tail. It is thought to be a fiber tract of the olfactory system. The relations of the corpus striatum to its sur-

[1] Lat. *lens*, a lentil. [2] Lat. *stria*, a streak or line.

rounding structures will be better understood when it is seen in the brain sections to be examined in Chapter IX.

In the consideration of the median sagittal section of the brain, it was stated that the fornix was composed of two kinds of fibers: one, the commissural, passing from one temporal lobe to the other, forming the posterior portion, or lyre; and the other, fibers which make up the fimbriæ and the anterior and posterior pillars, a transmission system for impulses between the temporal lobes and the optic thalami, the whole fornix being primarily concerned in olfaction. If the remainder of the corpus callosum is now removed, almost the entire fornix may be seen, and it will be understood how each fimbria, passing upward and forward along the floor of the inferior horn, forms a portion of the floor of the body of the lateral ventricle as well, and unites with its fellow from the opposite side to form the body of the fornix. The fimbria, enlarging as it ascends, is continuous with the concave border of the hippocampus along its entire length and, with the latter, encircles the optic thalamus beneath.

Morphologically, this portion of the fornix is the original ventromesial margin of the cerebral vesicle; it forms, therefore, a portion of the exterior of each cerebral hemisphere, which we have seen is everywhere else composed of gray cortical material. The cortex, however, stops short in the hippocampus and this surface of the hemisphere lying upon the optic thalamus (interbrain) is continued over to the caudate nucleus by the white matter of the fimbria, and by the thin ependyma which stretches from the free border of the fimbria to the nucleus. Thus the cerebral wall between the fimbria and the nucleus is reduced in thickness to one layer of cells, but it is, nevertheless, intact. The appearance of this area along the edge of the fimbria gives, however, no indication of the continuity of the wall, for the latter is everywhere pushed in by a dense fringe of small

arteries invested with pia mater, the choroid plexus of the lateral ventricle; and the ependyma, though still covering it, and morphologically excluding it from the ventricle, cannot be discerned by the naked eye. As stated in Chapter II, the velum interpositum, containing the blood vessels which make up the plexus, enters in the transverse fissure, the lateral extension of which is the choroid fissure, the latter being none other than the infolding of the ependyma between the fimbria and the caudate nucleus.

There are several large veins seen on that surface of the caudate nucleus protruding into the lateral ventricle, which carry away the blood from the interior of each hemisphere. These enter larger veins, pass mesially in the transverse fissure, being enclosed in that portion of the velum interpositum which overlies the third ventricle, and finally pass backward out of the transverse fissure in one vessel, the great vein of Galen, which in turn empties into the confluens sinuum (described in Chapter III). If the velum interpositum has not been pulled out when removing the brain, all these structures may be seen by cutting the anterior pillars of the fornix between the heads of the two caudate nuclei and reflecting the fornix back. This dissection lays open the foramina of Monro, their position being indicated by the junction of the groove between the caudate nucleus and the optic thalamus on either side, with the small hole leading downward into the third ventricle just anterior to the middle commissure (between the thalami). It will be readily understood, moreover, how this whole area of the cerebral hemispheres lies upon the optic thalami of the interbrain, and how the velum interpositum enters the choroid fissure and at the same time forms the roof for the third ventricle, which is to be seen just beneath it. The further consideration of these parts, especially the thalamus, will be taken up in the next chapter.

Some confusion has probably arisen in the use of the

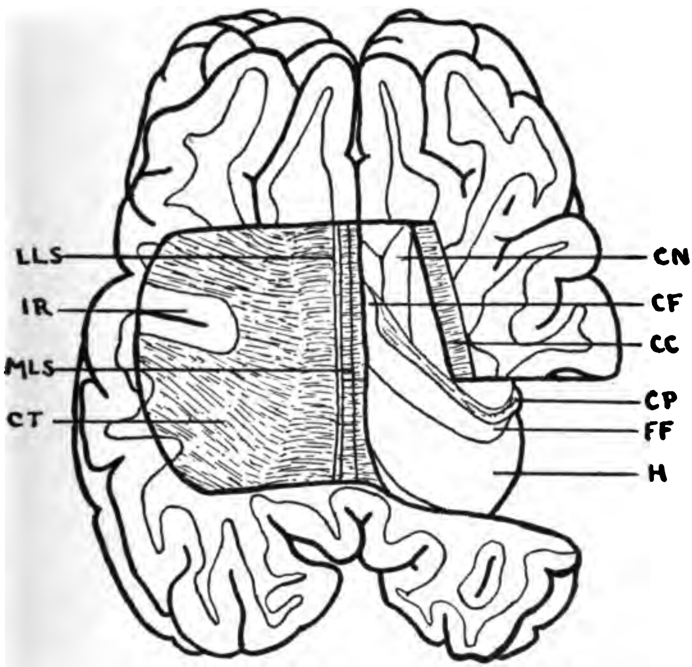


FIG. 10.—DISSECTION OF CORPUS CALLOSUM AND LATERAL VENTRICLE

CC, corpus callosum
CF, body of the fornix
CN, caudate nucleus
CP, choroid plexus
CT, fibers of the corpus callosum dipping into the temporal lobe
FF, fimbria
H, hippocampus
IR, cortex of the island of Reil
LLS, lateral longitudinal striæ
MLS, median longitudinal striæ

terms hippocampus and hippocampal gyrus. The latter, seen on the lateral and ventral aspects of the brain is, more properly speaking, the gyrus of the hippocampus; while the hippocampus proper is the elevation to be seen on the floor of the inferior horn of the lateral ventricle produced by the dentate [hippocampal] fissure. This fissure is one of the very earliest to appear on the cerebral hemisphere (see Chapter II), running around on the mesial surface of the temporal lobe; by pushing a complete fold of the cerebral wall into the ventricle, it becomes one of the so-called total fissures of the brain. The hippocampus is also known as the horn of Ammon, and the hippocampus major, to distinguish it from the hippocampus minor [calcar avis], a similar elevation seen on the floor of the posterior horn of the lateral ventricle in the human brain, produced by the calcarine fissure. There being no posterior horn or corresponding fissure in the sheep's brain, the latter possesses no hippocampus minor; the hippocampus major may therefore be known as the hippocampus, the name being derived from the resemblance of a cross section of this elevation to the form of a sea horse. On the floor of the inferior horn the hippocampus appears as a smooth white convolution running down to the tip of the horn, where it is slightly enlarged and is known as the pes[1] of the hippocampus [digitations of the hippocampus]. Its concave border is continuous with the fimbria, which, in fact, arises from the gray matter of the hippocampus concealed beneath the white medullary portion seen in the ventricle.

If now the entire hippocampal gyrus is cut across near the middle line and the outer portion removed from the thalamus (the separation being made, therefore, in the line of the transverse fissure) the mesial surface of this section may be studied and the relations of its white and gray matter

[1] Lat. *pes*, foot.

understood (see Directions *D*). On the under side of the part removed, the prominent fissure is the dentate, posterior to which is the mesial portion of the cortex of the hippocampal gyrus, which has curved around from the outside, while anterior to it the dentate gyrus and fimbria are to be seen. On looking at the cut end of this piece, these relations will be cleared up. The cortex of the hippocampal gyrus is seen to be pushed into the ventricle by the dentate fissure; the latter, coiling upon itself, carries the cortex with it, giving it the characteristic "sea-horse" appearance. The cortex, however, ends abruptly after it has thus been turned in on itself, and the anterior portion of the section consists of the white matter interior to the cortex and the white matter of the fimbria with which it is continuous. (Reference should be made to the illustrations of brain sections I, II, 4 and 5, on which all these parts are clearly shown.)

The dentate gyrus is the long narrow transversely fissured fold of gray matter just anterior to the dentate fissure, formed by the roll of the hippocampal cortex (the anterior end of the "sea horse"). This gyrus widens as it approaches the tip of the lobe and ends in a sharp angle formed by the sudden turning upward and backward of the tip of the hippocampal gyrus. This hooklike process is known as the uncus [1] and is the most definitely localized olfactory center in man. Above, in that portion of the hippocampus still attached to the middle cerebral wall, the dentate gyrus is continuous with the anterior part of a small lobe of gray matter, the fasciola cineria, underlying the splenium of the corpus callosum. In man, this is considerably atrophied, but nevertheless, as in the sheep, serves as a connection between the dentate gyrus and the longitudinal striæ on the dorsal surface of the corpus callosum, as observed in the first part of this chapter. The part of the

[1] Lat. *uncus*, hook.

fasciola cineria behind the dentate fissure (which is carried up onto it), is continuous with the hippocampal gyrus and may be considered analogous to the isthmus of the fornicate gyrus in man, connecting the hippocampal gyrus below with the gyrus cinguli above, thus preserving the continuity of the limbic lobe. The sections of this region which follow will clear up any doubtful points as to its anatomy, but if the directions and text have been carefully followed, the student should already have a clear idea of the relations of the hippocampus to the ventricle on the one hand, and to the cerebral wall on the other.

DIRECTIONS: *A*. With the long knife slice off the top of the cerebral hemispheres at the level of the dorsal surface of the cerebellum, but with the anterior end of the section lower than the posterior, on a line parallel to one drawn from the ventral surface of the olfactory lobe to the ventral surface of the hippocampal gyrus.

B. Insert the fingers into the longitudinal fissure at the top of the corpus callosum, and hooking the fingers under the gyrus cinguli, the gray matter above the corpus callosum should be ripped outward, exposing the surface of the latter. If one longitudinal and two transverse cuts are made on each side, corresponding to the dissection of the left hemisphere shown in the photograph (Fig. 10), a better result will be obtained.

C. On one side the corpus callosum should be cut through in a sagittal direction just to the side of the middle line and a similar incision made about a half inch lateral to the first, allowing the knife to go no deeper than a quarter of an inch. Cut across between the two at the posterior end and lift this flap forward, exposing the lateral ventricle. Insert the handle of the scalpel or other blunt instrument outward and downward from the posterior end of the ventricle; it should pass easily downward in the inferior horn, and by incising the cerebral wall down to the instrument in two places, a block of the temporal lobe may be lifted out and the whole inferior horn exposed.

D. Cut the occipital lobe away from this same hemisphere, pass a finger into the transverse fissure under the hippocampal gyrus, and cut down to it across the fimbria and hippocampus near the middle line of the brain, lifting this part away. Drawings should be made of the corpus callosum, the floor of the lateral ventricle, and of the mesial side of the temporal lobe, showing the cross section of the hippocampus.

VIII

THE INTERBRAIN AND THE BRAIN STEM

WHEN all the portions of the cerebral hemispheres above the levels of the optic thalami have been removed (according to directions), the dorsal surfaces of the interbrain and midbrain are exposed. If the student has been fortunate enough to preserve the velum interpositum, this is seen stretching across the middle line between the two thalami, forming a roof for the cavity between them, the third ventricle. The morphological roof of this ventricle consists principally of a single layer of epithelial cells, the ependyma, or lining of the ventricle, which alone remains at this point, in a similar manner to the thinning out of the floor of the lateral ventricle, as seen in the last chapter. Here too, the ependyma is pushed inward by the velum interpositum, forming the choroid plexus of the third ventricle. When the velum is withdrawn, the ependyma is necessarily withdrawn with it, and the ventricle becomes roofless. The removal of the velum fully exposes the dorsal surfaces of the optic thalami, the prominent, highly developed walls of the interbrain. They are united at their center by the middle commissure and form a support for the fimbriae as the latter arch backward along the floor of the lateral ventricle. Upon their dorsal surface the two habenulæ pass backward toward the pineal body, which lies in a cradle formed by the two thalami in front and the two superior corpora quadrigemina behind. If the cerebellum is also removed, the inferior quadrigemina may be seen

below the superior, these four bodies representing the roof of the midbrain.

By tearing what remains of the anterior pillars of the fornix away from the forward end of the thalami, the anterior commissure (described in Chapter VI) will be seen as a white band stretching across the middle line and entering the cerebral substance on each side just beneath the caudate nuclei. Behind it, the point of junction of the mesial surfaces of the thalami is known as the middle commissure, which is really no commissure at all, as it is largely composed of gray matter in which very few fibers cross the middle line. Between the middle and the anterior commissures an opening indicates the extension of the ventricle downward under the middle commissure, as may be ascertained by passing a probe downward and backward until it emerges through the infundibulum on the ventral surface.

The forward extremity of each thalamus is known as its anterior tubercle, the portion opposite the middle commissure its body, and the prominent projection posteriorly and laterally the pulvinar.[1] The thickening of the habenulæ as they pass backward form the ganglia (nuclei) of the habenulæ, and just before they reach the pineal body they are connected in the middle line by the commissure of the habenulæ, anterior to which, between the ganglia, is the pineal recess of the third ventricle. By raising the pineal body, the pineal lamina is seen extending downward in front of the superior corpora quadrigemina; a transverse fold just behind its base represents the position of the posterior commissure.

If the lateral portion of one of the cerebral hemispheres has not already been removed, this should now be done, and the side of the inter- and midbrains examined. The optic tract, arising from the chiasm on the ventral surface,

[1] Lat. *pulvinar*, couch.

widens as it ascends around the crura, and becomes continuous dorsally with the pulvinar. Beneath the pulvinar, and appearing as an intrinsic part of the general structure, is a rounded eminence, the median geniculate [1] body; a less noticeable elevation anteriorly to this, on the tract itself, is the lateral geniculate body. Behind the tract, median geniculate and pulvinar, a ribbonlike band of fibers passes from under the pineal body around to the ventral surface of the crura, the transverse peduncular [2] tract. Behind this is seen the lateral aspect of the superior and inferior corpora quadrigemina, their prolongations forward to the optic tract being known as the superior and inferior brachia of the quadrigemina. The entire ventral aspect of this region is principally made up of the crura of the cerebrum, which morphologically form the floor of the midbrain. Passing mesially to the optic tract, the fibers of the crura extend to the cortex of the hemispheres, constituting the greater part of the internal capsule of the corpus striatum, and the corona radiata.[3]

The anatomical relations of these structures having been noted, it will be well to consider their physiological significance and more intimate relations to one another, before continuing with the posterior portion of the brain stem. The crura may be considered as that portion of the brain stem included between the optic tract in front and the pons behind. They are made up in part by all the fibers passing from cell bodies in the cerebral cortex and in the basal ganglia (*i.e.* corpus striatum, optic thalami, etc.) to the nuclei situated in their substance, in the pons, medulla oblongata, or cord — for the most part motor in function,

[1] Lat. *geniculare*, to bend the knee (from the resemblance of these bodies to bent knees).

[2] Lat. *pedunculus*, a little foot (passing across the crura or peduncles).

[3] Lat. *corona radiata*, radiating crown (radius, a spoke).

the great bundles passing from the general motor areas of the cortex lying in the crustæ[1] [base of the peduncles], the most ventral parts of the crura. They are likewise made up of all the sensory fibers passing out from the cell bodies of the cord, medulla oblongata, and pons to the basal ganglia and cortex, making relays between the ganglia as they ascend,[2] the general sensory fibers from the body occupying a position dorsal to the general motor, in that part of the crura called the tegmentum.[3] Thus the fibers of all but the olfactory and optic systems (and, indeed, a few fibers from these) run in these great transmission bundles.

Beyond this (*i.e.* superior to the crura in the brain of the primates, but anterior in the brain of other mammals, as the sheep) the motor and sensory paths of the crura form the internal capsule of the corpus striatum, passing between and breaking up the solid ganglia of the caudate and lenticular nuclei, thus giving them a striated appearance. This may be seen in brain sections through this region, and if the present dissection is continued as directed, by making a parasagittal section anterior to the optic tract, the fibers of the internal capsule may be plainly seen as they pass through the corpus striatum and radiate toward the cortex. The corpus striatum, while relatively of less importance in those animals possessing a well-developed cerebral cortex,

[1] Lat. *crusta*, crust or covering.

[2] A few words which have reference to the passage of fibres or impulses in an upward or downward direction between regions of the human brain, have been retained because of their significance from a physiological standpoint and their practical application to the brains of other mammals. In general, however, terms have been employed expressive of the anatomical relations in the sheep, where the brain stem and cord are horizontally behind the cerebrum, that the student may not be confused at this point by terms descriptive of the human brain, where the cerebrum is superior, rather than anterior, to the other parts.

[3] Lat. *tegere*, to cover; a covering.

is, nevertheless, an essential structure in every mammalian brain. Its cell bodies form important relays for the fibers which pass through it in the internal capsule, and especially for a great group of fibers passing into it from the cortex, thence being relayed to the optic thalamus. This latter bundle, the strio-thalamic tract, forms a very important connection between the forebrain and interbrain, especially in the lower forms, where it is very noticeable.

While the corpus striatum becomes relatively smaller with the development of the cerebral cortex, the thalamus becomes much larger. The function of the thalamus in the lower vertebrates is somewhat obscure, being evidently connected to the early olfactory system, though not an important center for smell. In mammals it becomes an adjunct of the cerebrum, and is an important relay station for sensory impulses passing from the sense organs and lower centers to the cortex. Many reflexes may, however, be completed through the thalamus without the aid of cortical connections. Therefore, although many of the motor bundles from the cortex run directly under the thalamus to the lower centers, without relaying, it must nevertheless be considered a great receiving and distributing station for the sensory fibers passing into it from the crura (afferent) and for many fibers from the corpus striatum (efferent). Its cells send out large bundles of fibers which continue onward in the internal capsule and are distributed to the general and special sensory areas of the cortex.

The internal capsule, giving off and receiving fibers from the nuclei of the corpus striatum on either side, spreads out between these nuclei and then continues upward, expanding in all directions to all parts of the cortex, as the corona radiata. The frontal part of the capsule is made up of the projection fibers from the frontal lobe, including the

great pyramidal bundle from the general motor area, the latter occupying also the anterior two-thirds of the occipital part of the capsule. The occipital part is also composed of the general sensory fibers, from their relay in the thalamus to the somæsthetic area in the cortex, mingling with the motor fibers. The internal capsule is also made up of fibers passing between the caudate and lenticular nuclei, and from these nuclei to the thalamus, as has been seen.

The corona radiata consists of all the fibers which, either originating in, or ending in, the cerebral cortex, emerge from the cerebral hemispheres or enter them from below through the internal capsule. It does not, therefore, contain the auditory tracts from the midbrain (inferior corpora quadrigemina) and median geniculates to the temporal cortex, or the fibers from the lower optic centers passing to the visual area in the occipital cortex, the optic radiation, which is situated behind and lateral to the capsule, and may be considered as separate from the latter. The corona radiata makes up a large part of the centrum semiovale of each hemisphere, mingling with the commissural fibers of the corpus callosum and the association fibers connecting different cortical areas.

We must now consider the optical apparatus, the lower centers of which lie in the inter- and midbrains. Sensory impulses arising in the retina of each eye travel upward in the optic nerves, through the optic chiasm and into the optic tracts, thence to the lateral geniculate body, the pulvinar of the thalamus, the superior corpora quadrigemina, and thence to the occipital cortex by the optic radiation [occipito-thalamic radiation], which passes forward, upward and backward from each thalamus. The position of these structures has already been considered, but their more complex structure and connections remain to be examined. In many of the lower animals, as fishes (and even in birds),

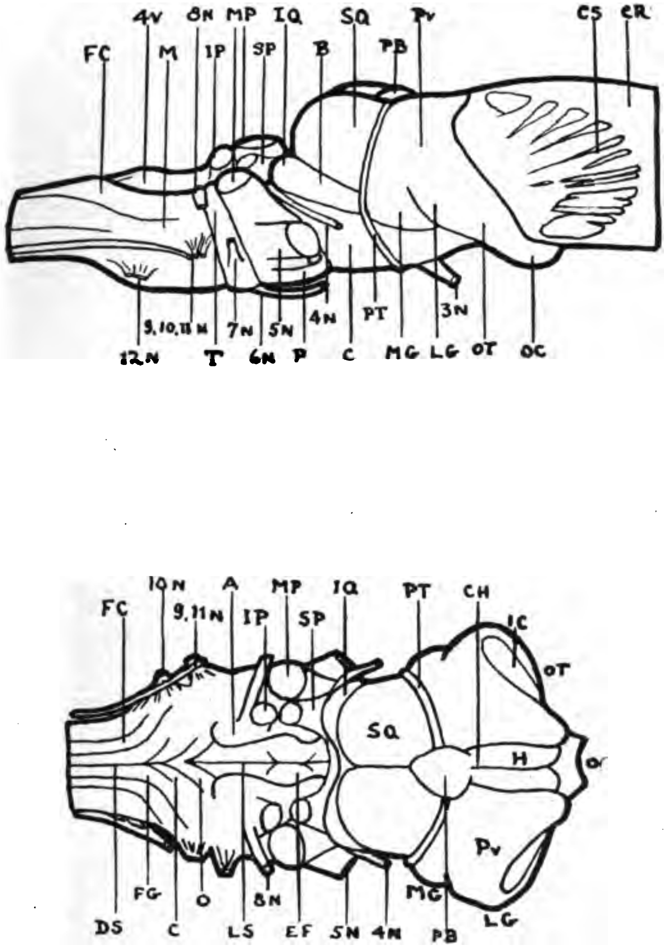


Fig. 11.—Lateral and Dorsal Aspects of the Brain Stem

A, acoustic tubercle
B, brachia of inferior quadrigemina
C, crus
CH, commissure of habenulæ
Cl, clava
CR, corona radiata
CS, corpus striatum
DS, dorsal sulcus
EF, facial eminence
FC, fasciculus cuneatus
FG, fasciculus gracilis
H, habenulæ
IC, internal capsule
IP, inferior cerebellar peduncles
IQ, inferior corpora quadrigemina
LG, lateral geniculate body
LS, longitudinal sulcus
M, medulla oblongata
MG, median geniculate body
MP, middle cerebellar peduncles
O, obex
OC, optic chiasm
OT, optic tract
P, pons
Pv, pulvinar
PB, pineal body
PT, transverse peduncular tract
SP, superior cerebellar peduncles
SQ, superior corpora quadrigemina
T, trapezoid body
4 v, 4th ventricle
3–12 n, 3d–12th cranial nerves

these lower centers and tracts are relatively enormous, indicating that the great dependence of these creatures upon the sense of sight is entirely reflex or instinctive, and that only in birds, where the primary optical system is first connected with the cortex, do we begin to find provision for intelligent coördination with this sense. In the lower animals, moreover, where the eyes are situated upon the sides of the head, all the fibers of one optic nerve cross in the chiasm and pass on in the optic tract of the opposite side, following the general principle of crossed innervation. In higher forms, however, with eyes placed nearer the front, and so acting in coördination, many of the outer fibers of each nerve continue on the same side. This is thought to be caused by the fact that in the latter case the visual fields partially overlap, while in the former they are entirely separate. Thus in man, only the fibers of the inner halves of the optic nerves decussate in the chiasm.

Collaterals [1] of the fibers in the optic tracts pass into the lateral geniculate bodies, and the fibers themselves continue upward and backward into each pulvinar, and into the superior quadrigeminal bodies through their brachia, which extend backward from the lateral geniculates to them. It is therefore seen that the optic thalami of all the mammals are concerned with vision as well as forming relays for the fibers of the crura and internal capsule, although the posterior of the great nuclear masses which make them up are more especially involved in the optic system. The white appearance of the thalami is due to a thin covering of fibers which passes backward over them from the optic radiation anterior to their dorsal surface, finally being lost in the optic tracts. Some of these fibers penetrate the thalami, and the whole layer, called the stratum zonale,[2] is thought

[1] Lat. *con*, together, and *lateralis*, of the side; side branches.
[2] Lat. *stratum*, a pavement, and *zona*, zone or girdle.

to constitute a part of the optic pathway. Similarly, the geniculate bodies and the superior quadrigemina have a white exterior due to an investing fiber layer, so that these parts of the brain stem appear lighter than would be supposed from the fact that they are largely made up of gray nuclei.

In the lower vertebrates the quadrigeminal center for vision is relatively of greater size and importance; in some animals it is probably the highest center possessed. As the visual cortex is developed, however, fewer fibers pass from the lateral geniculate to this primary center, while the lateral geniculate and the pulvinar become larger and receive the greater share of the incoming impulses. Thus, in man, only a few fibers pass via the brachia of the superior quadrigemina to the cells in the latter, from which they are relayed back again through the brachia and join the other fibers of the optic radiation, being concerned in ocular and pupillary reflexes. The greater part of the radiation therefore originates in cell bodies located in the lateral geniculate and the posterior portions of each thalamus, and, leaving these nuclei in tracts dorsal and lateral to the internal capsule (posterior in man), passes to the occipital cortex. Fibers have also been demonstrated to arise in this cortex and pass down these pathways to the primary centers, relaying to the motor nerves which move the eyes; they form, therefore, the efferent limb of a higher center reflex for vision.

Certain structures in this neighborhood remain to be discussed. Neither the inferior corpora quadrigemina nor the median geniculate bodies are concerned with vision, though from similarity of name and location the student might naturally associate them in function with the superior corpora quadrigemina and the lateral geniculates. The inferior quadrigemina are found in lower forms as small ganglia in the base of the superior, which are always well

developed. In higher forms, however, these develop into well-marked elevations, the inferior quadrigemina (misnamed posterior optic lobes), and evidently form one of the primary centers for hearing. Auditory impulses entering by the eighth nerve, which is seen on the dorsolateral aspect of the medulla, cross the middle line in fibers running either beneath the floor of the fourth ventricle (forming the acoustic striæ), or through the trapezoid body on the ventral surface. Hence they pass forward, as the lateral fillet[1] or lemniscus,[2] through the superior peduncles of the cerebellum to the inferior quadrigemina. Some fibers also pass to the median geniculates by the brachia of the inferior quadrigemina, so plainly seen on the lateral surface of the midbrain. Through the brachia and directly from the geniculates, after relaying, the fibers are carried on to the temporal cortex in a bundle lying on the outer side of the internal capsule. It is possible that the inferior quadrigemina are connected to each other by a continuation of their brachia down the optic tract and around behind the optic chiasm, forming the inferior, or Von Guden's, commissure.

The ganglia of the habenulæ are to be seen in this region; they are formed of cells which make relays with fibers arising from the olfactory cortex at that part of the hemispheres near the base of the interbrain. These pass upward on the anterior and dorsal surfaces of the thalami near the middle line, and are termed the tænia[3] thalami. From the habenular ganglia, fibers extend to the midbrain region, so that the tænia must be considered a pathway from the olfactory apparatus to the inter- and midbrains. Behind the ganglia and in front of the pineal body, a small transverse bundle constitutes the commissure of the habenulæ, and from it the peduncles of the pineal body arise. The pineal

[1] Fr. *filet*, a thread. [2] Gr. *lĕmniskos*, fillet or thread.
[3] Gr. *tainia*, band or ribbon.

body is the remnant of the stalk which passes to the parietal eye in reptiles, and in the higher animals it takes on a glandular structure, probably producing an internal secretion of unknown function.

The lateral and ventral surfaces of the remainder of the brain stem were examined in Chapters IV and V, and it suffices to study the dorsal surface only, to complete the exterior of this region. The cerebellum should have already been removed, exposing its peduncles and the interior of the fourth ventricle, of which it forms a large part of the roof. There are three pairs of peduncles, the superior [brachia conjunctiva], middle [brachia pontis], and inferior [restiform bodies], the cerebellum appearing to be supported on them. Little is known of the distribution of their fibers at the cerebellar end, and, in fact, still less is understood of the arrangement of the fiber tracts connecting the cells of the cerebellar cortex. So far it has been ascertained that this highly developed roof of the midbrain receives fibers from the spinal cord, the medulla oblongata, mid- and interbrains, and indirectly from the cerebral cortex, and that fibres probably pass from it to these other brain regions. The nerves of equilibrium also find endings in the cerebellum, making it probable that this region is principally concerned with the coördination of the body and the maintenance of muscle tone, a view that has been supported by the observation of animals and human beings whose cerebelli have been injured or destroyed.

The superior cerebellar peduncles emerge from the white matter of the cerebellum mesially to the other two peduncles on each side; they pass forward (or upward in the human brain), converging toward the middle line and disappearing beneath the inferior quadrigeminal bodies at the point where the fourth cranial nerves emerge. They contain efferent fibers which originate for the most part in the dentate

nucleus, a mass of gray matter situated just below the center of the medullary substance of the cerebellum, although some of the fibers may originate directly from the cells of the cerebellar cortex. On entering the midbrain the greater part of these fibers decussate to the opposite side, most of them terminating in two large ganglia, the red nuclei, situated in the dorsal portion (tegmentum) of the crura, just behind the thalami. From here these fibers relay to the thalamus and cortex, forming a part of the general sensory path. The red nuclei send some fibers back over the same path to the cerebellum (afferent to the cerebellum) and others backward into the spinal cord — the latter may be relays for efferent fibers originating in the cerebral cortex, or for the efferent cerebellar fibers of the superior peduncles.

The middle peduncles leave the cerebellum laterally to the other two and are much larger. They pass downward on either side of the brain stem, becoming continuous with the pons. Their fibers are both efferent and afferent, and pass between the cerebellar cortex and the nuclei of the pons. From these nuclei, fibers may pass either upward or downward across the brain stem, connecting the two halves of the cerebellum; in animals with a small cerebellum, the pons is correspondingly small. The pontal nuclei form many important connections with the nuclei of the cranial nerves in this region; also, in the higher mammals, they probably receive fibers from the cerebral hemispheres (from the frontal and temporal lobes in man), which, relaying to the cerebellar cortex, form an important fiber system from the cerebrum to the cerebellum (the fronto-ponto-cerebellar and temporo-ponto-cerebellar tracts in man).

The inferior peduncles are smaller than the other two, and leave the cerebellum between them. They pass backward (or downward) into the dorsal surfaces of the medulla laterally to the fourth ventricle, where they are known as

the restiform bodies. Their construction is complex, and it will be only necessary to note that fibers from the direct cerebellar tract [fasciculus cerebellospinalis] of the spinal cord enter most largely into their composition, together with others from nuclei of the medulla on the same and opposite sides, most of these fibers carrying impulses of muscle sense to the cerebellum. The inferior peduncles also contain efferent fibers which pass to the cord, either directly or by relaying in the medulla, forming the principle pathway from the cerebellum to the muscles.

Between the peduncles on either side is the diamond-shaped cavity of the hind- and afterbrains, the fourth ventricle or rhomboid fossa,[1] which communicates with the rest of the ventricular system by the aqueduct of Sylvius in front, and is continued posteriorly as the central canal of the medulla oblongata and spinal cord. As the other ventricles, it is entirely lined with the thin ependyma. Its roof is formed from before backward by the anterior medullary velum, the inferior vermis of the cerebellum, and the posterior medullary velum. The roof is also partly formed in front by the inner sides of the superior cerebellar peduncles, between which the anterior velum is stretched. The latter is largely made up of nerve fibers which form an important efferent tract to the cerebellar cortex from the cord, the path ascending to this point and then turning backward into the cerebellum, via the superior peduncles. The anterior and posterior medullary vela have probably been lost with the removal of the cerebellum.

The sides of the fourth ventricle are formed by the superior peduncles, the acoustic[2] tubercles (two large eminences in which the eighth nerves end), and farther back by the restiform bodies, by the anterior terminations of the

[1] Gr. *rhombos*, romb, and *eidos*, like; Lat. *fossa*, a ditch.
[2] Gr. *akoustikos*, pertaining to a thing heard.

cuneate [1] and gracile [2] tracts from the cord, and prominences known as the obex [3] and clava.[4] A median cleft, the longitudinal sulcus, divides the floor of the ventricle into two lateral halves, the obex preventing it from being continued directly backward as the dorsal sulcus of the medulla and cord. There are several important structures described in the floor of the human fourth ventricle which cannot be constantly detected in that of the sheep, the only exception being two small elevations on either side of the middle line in the anterior half, the facial eminences [colliculi facialis], beneath which the fibers of the seventh nerve are clustered. In man, a prominent bundle of fibers passes across the floor of this ventricle near its middle, the acoustic or medullary striæ, being a continuation of the auditory fibers from the acoustic tubercles to the opposite lateral fillets; in the sheep these cannot be seen. Under the floor of the ventricle are the nuclei of all the cranial nerves (except the first, second, third, and eleventh), and important fiber connections between them and other brain regions; some of them will be observed in the brain sections to follow. The whole posterior end of the floor of the ventricle is sometimes called the calamus scriptorius.[5]

Over the posterior end of the ventricle, the posterior medullary velum passes forward to the cerebellum, being very thin in the center, where it is pressed inward by the pia and blood vessels to form the choroid plexus of the fourth ventricle; it is also thin at its extreme edges where lateral choroid plexuses are found. A very important feature of this structure is its perforation by small foramina, that of Majendie [median aperture of the fourth ventricle] at the posterior angle of the ventricle, and those of Key and

[1] Lat. *cuneus*, a wedge.
[2] Lat. *gracilis*, slender.
[3] Lat. *obex*, a barrier or bar.
[4] Lat. *clava*, a club.
[5] Lat. *calamus scriptorius*, a writing pen.

Retzius [lateral apertures of the fourth ventricle], at the posterior lateral angles. These afford a communication between the ventricles and the subarachnoid space, thus equalizing the pressure of the cerebrospinal fluid in the ventricular system with that on the outside of the brain. This is a matter of considerable significance for the maintenance of conditions under which the brain can properly function.

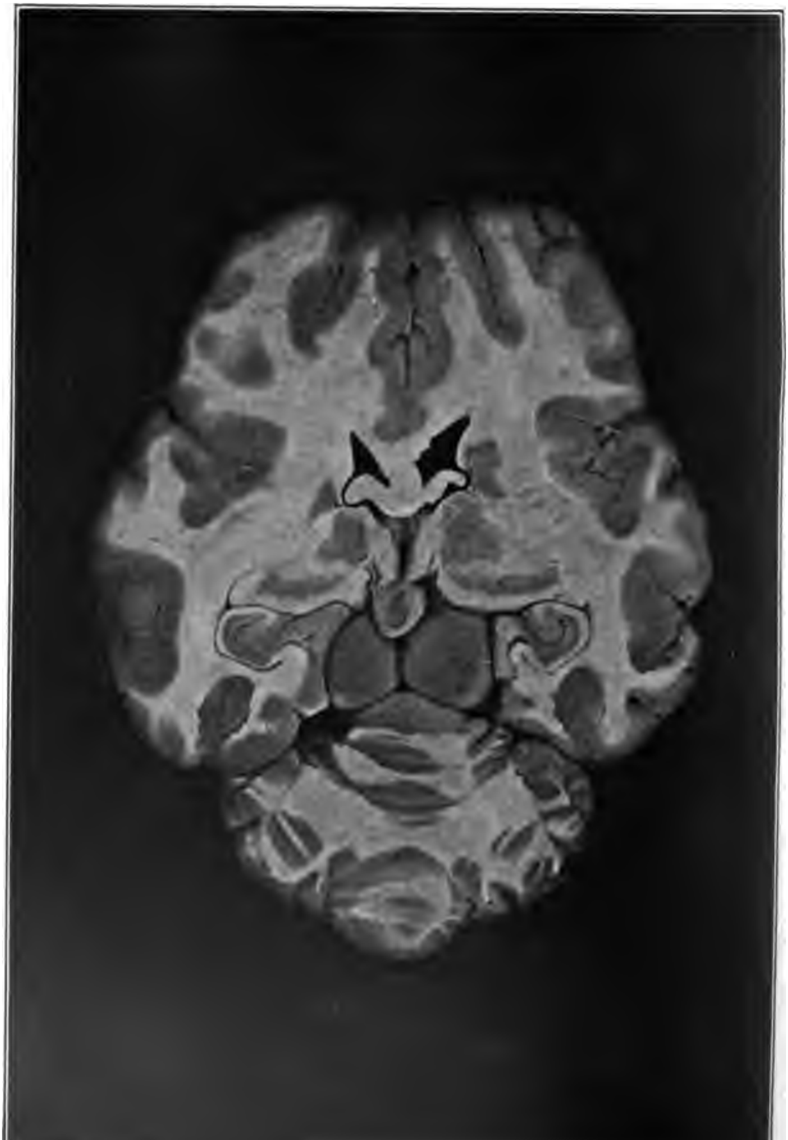
Directions: Tear the temporal lobes away from the brain stem, then make a shallow incision into the white matter along the anterior edge of each optic tract, insert the fingers into the cut, and tear the cerebral substance forward. This will expose the internal capsule and the corona radiata, showing the direction of their fibers. The cerebellum should be carefully lifted up and cut away at the closest possible point to its inferior surface, thus preserving the cerebellar peduncles, and, if possible, the anterior and posterior medullary vela. Strip the pia mater from this entire section, and carefully examine and draw the lateral and dorsal aspects of the interbrain and brain stem.

IX

HORIZONTAL AND TRANSVERSE SECTIONS

It is obvious that a series of sections through the brain in the sagittal, horizontal, and transverse planes would furnish an excellent understanding of its internal structure; in fact, no other dissection need be used if such sections were made close enough together and studied with due reference to one another. Of the great number of sections for choice, but two horizontal and seven transverse sections have been selected to elucidate the most important features which have been brought out in the preceding text. It is hoped that the student will make other sections between those which are described and illustrated here, as the knife very naturally fails to expose many significant structures which must be passed over briefly, or entirely omitted, in this necessarily cursory examination.

If a horizontal section is made at the top of the superior corpora quadrigemina, the knife will divide the cerebrum and cerebellum into almost equal horizontal halves, the dorsal portion of the interbrain also being sectioned. The characteristic disposition of the cortex and medulla of both cerebrum and cerebellum is very noticeable, the deep infolding of the cortex of the island of Reil being particularly prominent. Anteriorly, at the mesial termination of the deep longitudinal fissure, the white fibers of the corpus callosum are seen to stretch across the middle line, cut through the genu, near the rostrum. Behind the callosum,



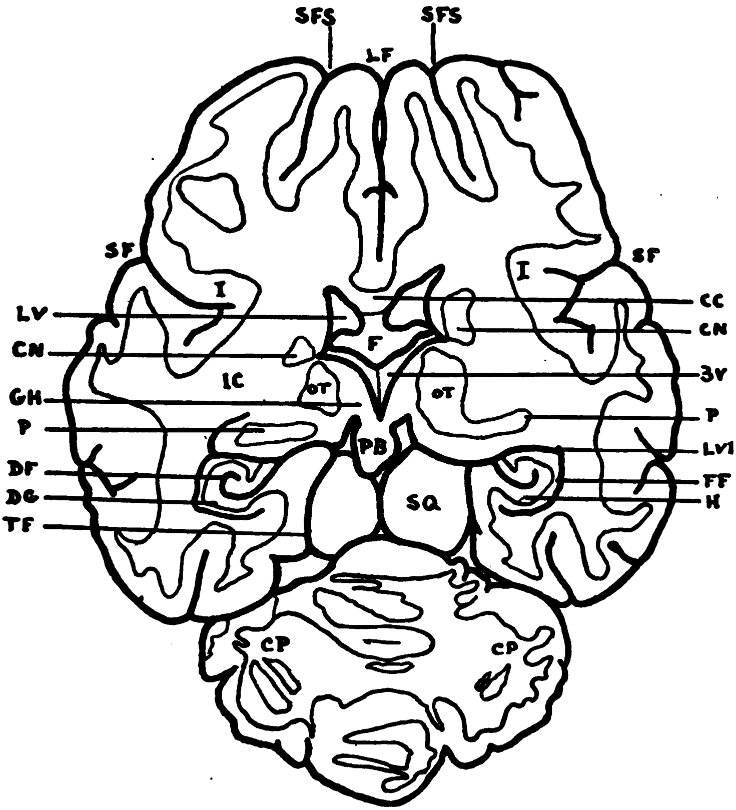


Fig. 12.—Horizontal Section I

CC, corpus callosum
CN, caudate nucleus
CP, peduncles of cerebellum
DF, dentate fissure
DG, dentate gyrus
F, fornix
GH, ganglia of the habenulæ
H, hippocampus
I, insula
IC, internal capsule
LF, longitudinal fissure
LV, lateral ventricle (body)
LVI, inferior horn of the lateral ventricle
OT, optic thalamus
P, pulvinar
PB, pineal body
SF, Sylvian fissure
SFS, superior frontal sulcus
SQ, superior quadrigemina
TF, transverse fissure

the body of the fornix is seen in close apposition, with the fimbriæ extending laterally from its ventral surface, as they leave the body to pass backward into the inferior horn of the lateral ventricle, forming a part of its floor all the way.

Between the corpus callosum above, the body of the fornix mesially, the fimbria ventrally, and the medullary wall laterally, is the central portion, or body, of the lateral ventricle, near the point where it becomes continuous with its anterior horn. The nuclear masses just lateral to the ventricle on either side are the dorsal portions of the caudate nuclei, which bulge into the ventricle below the plane of the section. Behind the fornix is the upper part of the third ventricle over which the fornix arches (above the plane of the section). At the bottom of this portion of the third ventricle, a small piece of the dorsal surface of the optic thalami is seen in the middle line, enclosed between the habenulæ, which the knife has cut throughout their length. Behind the habenulæ, the pineal body is sectioned, and behind that in turn lie the superior corpora quadrigemina just below the section level. At either side of the habenulæ, the exposed gray matter represents the nuclear masses of the thalami, the transverse bar posteriorly being the cut pulvinar.

The greater part of the bodies of the lateral ventricles lie above the section, but as they curve downward as the inferior horns they are again seen in section, the knife also cutting the structures of their floors. Thus the fimbria is seen to lie on the mesial side of the thin crack made by each inferior horn, and its relation to the gray matter of the hippocampus is very well illustrated. From the exterior, one of the limbs of the great transverse fissure enters laterally to the quadrigemina, and from it the dentate fissure passes laterally to separate the dentate gyrus from the hippocampal gyrus. The white medullary portion of the section is mostly made up of the fibers of the corona

radiata just above the level of the internal capsule; they are plainly seen lateral to the caudate nucleus and the thalamus, as they are broken up by the transversely disposed association and commissural fibers at this level.

A horizontal section made through the lower part of the inferior quadrigemina brings out the relations of some very important structures, especially the corpus striatum. The anterior end of the longitudinal fissure may be seen separating the two hemispheres as far back as the corpus callosum. The latter having been sectioned through the thickness of its rostrum, appears as a very thick band of fibers radiating to the frontal lobe as the forceps minor. From the center of its posterior surface, the thin septum pellucidum extends backward to the anterior columns of the fornix, which are cut transversely as they descend to the sides of the interbrain and the mammillary body. The anterior horn of the lateral ventricle, bounded anteriorly by the corpus callosum, mesially by the septum pellucidum, and laterally by the gray mass of the caudate nucleus, is seen as it passes downward to the olfactory lobe on each side.

The narrow white tract crossing the middle line at the posterior border of the pillars of the fornix is the anterior commissure, connecting the two olfactory lobes, as described in Chapter VI. Behind this, in the median line, a small opening indicates the anterior portion of the third ventricle, being separated from the corresponding posterior portion by the middle commissure, which is seen to occupy the middle line between the gray masses of the optic thalami on either side. The posterior commissure is seen to pass in front of the anterior ends of the inferior quadrigemina, which appear as two large bodies projecting backward to the cerebellum. The antero-lateral portion of these bodies may be seen to communicate with two well-marked nuclear masses, one

pair of which extends backward, the other outward, from the thalami. The former are the brachia of the inferior quadrigemina, and the latter are the median geniculate bodies; the significance of their connection was discussed in the previous chapter.

The corpus striatum occupies a large area of this section, being anterior and lateral to the thalamus. It has been so fully considered elsewhere that here it will be necessary to note its appearance only. The caudate nuclei are seen in two places on each side; anteriorly, as the two large gray masses forming the lateral walls of the ventricle, and posteriorly, just lateral to the extremities of the median geniculates, as smaller sections of their tails which have arched backward and downward over the thalami. The internal capsule is seen lateral to the caudate nucleus and the thalamus, comprising a frontal and occipital part, with its knee [genu] pointed mesially about opposite the anterior commissure. Lateral to its two parts is the lenticular nucleus, long and slender, its greater part lying on a lower level than that of the section. The lenticular nucleus can be separated into a large lateral part, the putamen,[1] and a smaller mesial part, the globus pallidus[2]; these divisions are much clearer in man. It can be readily understood from this section how the fibers of the internal capsule intermingle with the gray matter of these nuclei, which it passes between and practically encapsulates, and gives the characteristic appearance to the corpus striatum.

Outside the lenticular nucleus is a thin band of fibers, the external capsule, which also goes to make up the corona radiata above, and still farther laterally, an elongated nucleus appears, the claustrum,[3] beyond which is a thin

[1] Lat. *putamen*, a husk or shell.
[2] Lat. *globus pallidus*, pale sphere.
[3] Lat. *claustrum*, barrier.

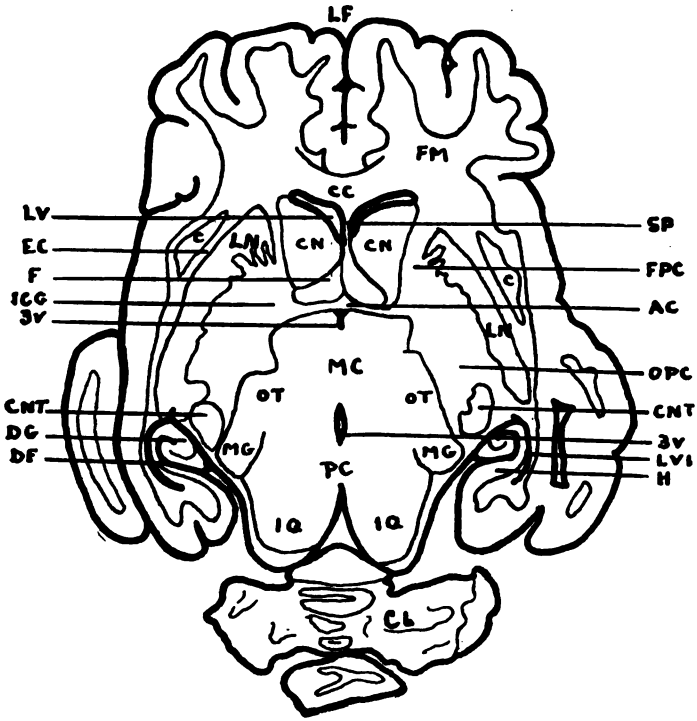


FIG. 13.—HORIZONTAL SECTION II

AC, anterior commissure
C, claustrum
Cb, cerebellum
CC, corpus callosum
CN, caudate nucleus
CNT, tail of caudate nucleus
DF, dentate fissure
DG, dentate gyrus
EC, external capsule
F, fornix
FPC, frontal part of internal capsule
FM, forceps minor
H, hippocampus
IC, internal capsule
ICG, genu of internal capsule
IQ, inferior corpora quadrigemina
LF, longitudinal fissure
LN, lenticular nucleus
LV, body of lateral ventricle
LVI, inferior horn of lateral ventricle
MC, middle commissure
MG, median geniculate body
OPC, occipital part of internal capsule
OT, optic thalamus
PC, posterior commissure
SP, septum pellucidum

band of medulla and the cortex of the insular region. The hippocampus is well seen in this section, which passes through its pes. The fimbria, being narrowed from above downward, has here entirely disappeared, while the dentate gyrus is larger than in the previous section. The dentate and transverse fissures, and inferior horn of the ventricle, are particularly well seen. Lateral to the ventricle, deep sulci have nearly separated the ventral tips of the temporal lobes from the remainder of the hemispheres. The cerebellum is to be noted sectioned near its base, the white areas at its sides clearly indicating the points of emergence of its peduncles. This is a very instructive section and should be most carefully studied.

QUIZ

The first of the transverse sections, in which important structures appear, should be made just posterior to the genu of the corpus callosum. Here a very vivid impression may be obtained of the great infolding which takes place in the cerebral cortex, such as may be produced by the longitudinal fissure, and splenial and first arcuate sulci. (The principle sulci are indicated in the diagrams accompanying these sections.) The thick fiber bundle of the corpus callosum forms the roof of this portion of the lateral ventricle, which is cut just behind its anterior horn. Below the ventricle, the ganglionic masses of the corpus striatum present a characteristic appearance, the large head of the caudate nucleus jutting into the ventricle, separated from the smaller end of the lenticular by the scattered fiber bundles of the internal capsule. In man, the nuclei of the corpus striatum are not, of course, relatively as large, owing to the much greater development of both cortex and medulla of the hemispheres. The thin septum pellucidum separates the lateral ventricles in the middle line and ends in the cortex below in the subcallosal region, the section being

just in front of the anterior pillars of the fornix. On the ventral surface of the section, below the lateral edges of the caudate nuclei, two small white spots are seen; these are sections through the white matter of the lateral olfactory roots.

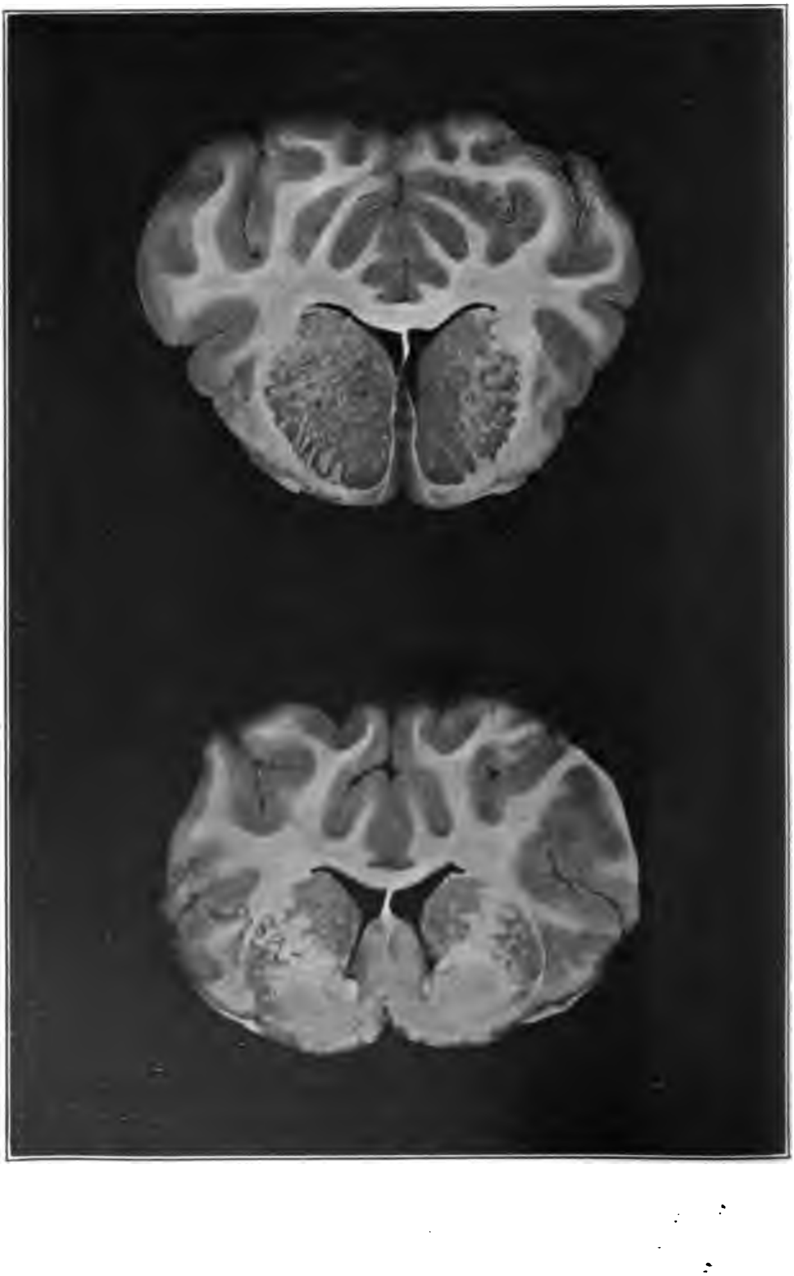
A very instructive section may be made through the pillars of the fornix, cutting through the cortex at about the location of the Sylvian fissure. The body of the corpus callosum is sectioned just forward of its middle, leaving a short piece of septum pellucidum between it and the fornix. The fornix pillars, arching forward and downward, have been cut in such a plane as to expose almost their entire vertical elevation, and may be seen slightly spreading into the interbrain wall to reach the mammillary bodies on the ventral surface of the brain (behind the plane of the section). Laterally to the septum and fornix are the bodies of the lateral ventricles, with the caudate nuclei jutting into their lateral walls.

At the ventral extremities of the ventricles the striae terminales are seen on either side as they follow the tail of the caudate nucleus backward. Below them, the internal roots of the olfactory lobes are seen passing backward to form the anterior commissure, which is just posterior to the plane of the section. Ventrally and laterally to these roots, the gray matter of the olfactory cortex is seen, corresponding to the anterior perforated space on the ventral surface; in fact, this area may be observed to be somewhat broken up by fine perforations where the bundles of arteries enter from below. The corpus striatum is again clearly shown in this section, the caudate nucleus having become smaller, and the lenticular nucleus and internal capsule, larger, than in the preceding section. Laterally to the lenticular nucleus lie the external capsule and claustrum, the infolded cortex of the island of Reil lying just above them.

The next section has been made through the middle commissure and the optic thalami, which appear as large gray rounded masses lying on either side of the middle line, just below the center. Above and below the middle commissure, the third ventricle has been opened; below, it extends downward to the bottom of the section, being here continuous with the infundibulum and pituitary body (which should lie beneath this portion of the ventral wall), while above, it spreads over the thalami to the point where they meet the lateral extension of the fornix. Here the fornix lies over the third ventricle and forms the floor of the lateral ventricle, its body having widened out with the fimbriæ, which pass backward over the thalami and become continuous with the hippocampi, as we have seen.

Between the fornix and the third ventricle lies the thin ependymal roof of the ventricle and the velum interpositum, which pushes the roof downward to form the choroid plexus; none of these structures have been preserved in the section illustrated, but it is hoped that the student will be more fortunate. The choroid plexus of the lateral ventricle passes laterally and upward around the lateral border of the fimbria, pushing ahead of it the ependymal wall of the ventricle, which morphologically stretches between the edge of the fimbria and the caudate nucleus. The latter is to be seen as a small gray mass at the outer angle of the ventricle; it is the tail of the nucleus as it passes backward to encircle the thalamus.

Lateral to the caudate nucleus, the knife has passed through the occipital part of the internal capsule, and it may be readily understood how its fibers, passing laterally and ventrally to the thalamus, continue backward in the crura (the latter having terminated anteriorly just behind the plane of the section). Outside the internal capsule the gray masses of the lenticular nucleus appear; they are still



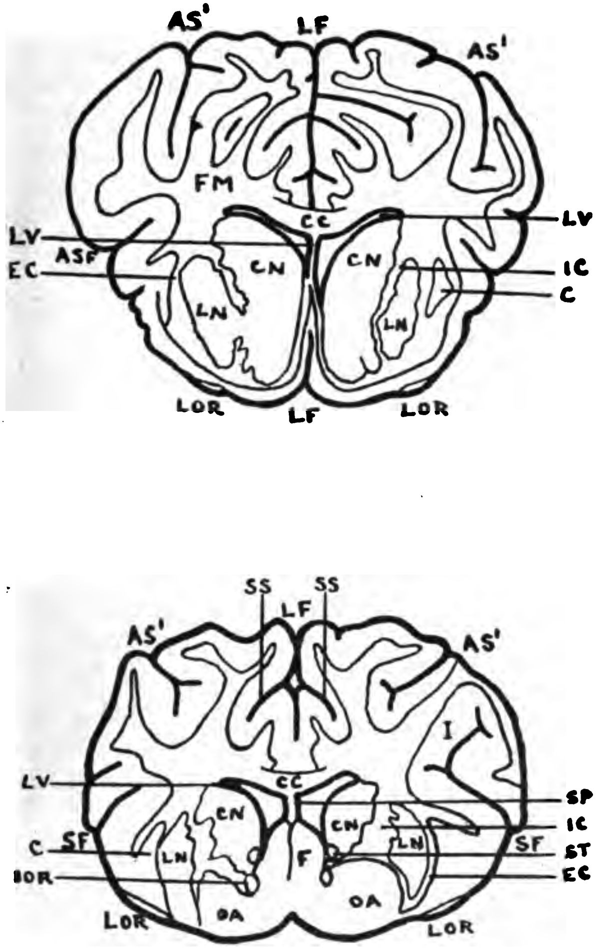


FIG. 14. — TRANSVERSE SECTIONS 1 AND 2

AS^1, 1st arcuate sulcus
ASF, anterior ramus of Sylvian fissure
C, claustrum
CC, corpus callosum
CN, caudate nucleus
EC, external capsule
FM, forceps minor
I, insula
IC, internal capsule
IOR, internal olfactory root
LF, longitudinal fissure
LN, lenticular nucleus
LOR, 'ateral olfactory root
LV, lateral ventricle
OA, olfactory area
SF, Sylvian fissure
SP, septum pellucidum
SS, splenial sulcus
ST, stria terminalis

quite large, and the internal capsule derives many fibers from this portion of the nucleus, as well as from the thalamus on its inner side. Still laterally to the lenticular nucleus lies the external capsule and claustrum, while beneath the nucleus at the junction of the temporal with the lower posterior portion of the frontal lobe, another large nuclear body appears. This is the amygdaloid [1] nucleus, which has not been previously mentioned; it is evidently connected internally with the olfactory cortex, and is much smaller in man than in the lower animals. Between this nucleus and the ventral extension of the fibers of the internal capsule, a well-defined fiber bundle represents a section of the optic tract passing backward around the thalamus from the chiasm, which is situated on the ventral surface anterior to the plane of the section (between this section and the preceding).

The white spots in the wall of the third ventricle below each thalamus indicate the points where the fibers of the fornix have turned upon themselves to pass upward to the thalami. The fiber bundles appearing as a white vertical line in each thalamus are the tæniae thalami, which ascend from the olfactory area to the ganglia of the habenulæ on the dorsal thalamic surface, posterior to the section.

The fourth transverse section, made through the mammillary body (two mammillary bodies are seldom seen in the sheep), passes through the posterior portion of the thalami, the pineal gland (or its brachia), and the fasciola cineria. The cerebral hemispheres are cut at about their greatest transverse diameter, a position which corresponds to the most anterior point at which the cerebrum is entirely separated from the interbrain and brain stem by the transverse fissure. In the section there is but one connection

[1] Gr. *amygdalē*, almond, and *eidos*, like.

which remains between them (other than those caused by the adhesions of the vessels and pia mater in the fissure), this being produced by a few fibers posterior to the internal capsule on the right side, which are passing backward from the thalamus to the occipital cortex — the optic radiation. The inferior horn of the lateral ventricle is here opened almost its entire length, as the section is made just where it passes downward into the temporal lobe; on the right side, the ventricle passes behind the fibers just mentioned.

The body of the ventricle is also shown between the corpus callosum above and the hippocampus and the fimbria below, the latter forming the floor of the inferior horn throughout the section, until it merges into the gray matter of the pes hippocampi. Above, the fimbria is cut off before it reaches the middle line, and it must be supposed to pass forward to join its fellow and form the body of the fornix. The dorsal portions of the hippocampi meet in the fasciola cineria just beneath the splenium of the corpus callosum; their relation to the fasciola cineria was explained in Chapter VII.

This section passes through the posterior portion of the interbrain and the anterior part of the midbrain floor; therefore the thalami are seen to be sectioned through their widest part (the pulvinar), and the crura appear below them. At the dorso-mesial border of the thalami, the ganglia of the habenulæ are seen, the connection between them being their commissure (the pineal body is posterior to the section). Above and below the habenulæ, the narrow cleft of the third ventricle appears, extending downward almost to the mammillary bodies. Laterally to the thalami, the white fibers of the optic tract are seen leaving these nuclei and the gray masses outside the tract, the lateral geniculate bodies, over which passes the thin layer of the stratum zonale.

On the ventro-lateral margin of the interbrain, white fiber bundles are observed running vertically to the plane of the section; these are the ventral portions of the crura, the crustæ, in which the efferent fibers from the cortex and internal capsule pass beneath the thalami on their way to the lower centers. In man, fibers from the frontal region of the cortex occupy that portion of the crustæ nearest the middle line; laterally to them, and occupying the greater part of each crusta, are the general motor fibers, the so-called pyramidal tract; and the outer fifth of each crusta is made up of efferent fibers from the temporal cortex. In the sheep, however, the crustæ are much smaller, the fibres from the cortical areas, especially the frontal, are fewer, and the greater part of each crusta is occupied by an almost black substance of unknown function, the substantia nigra.[1] This runs the length of the crura and serves to separate the crustæ below from the tegmentum above, the latter consisting for the greater part of the afferent sensory fibers and their nuclei. Just above the substantia nigra in the tegmentum, two dark masses may be faintly seen — they are the anterior ends of the red nuclei, which are important as relay stations for the fibers of the superior cerebellar peduncles, which carry sensory impulses to the thalamus and cortex. Fibers from cells in the red nuclei also pass downward through the midbrain and medulla oblongata into the cord, and some also pass backward into the cerebellum through the superior peduncles. Below the crustæ the third cranial nerves appear, cut off at a point a short distance anterior to their origin in the crura.

In the following sections, the important elements are poorly differentiated and many of them will be made out only with great difficulty. The brain stem is one of the

[1] Lat. *substantia nigra*, black substance.

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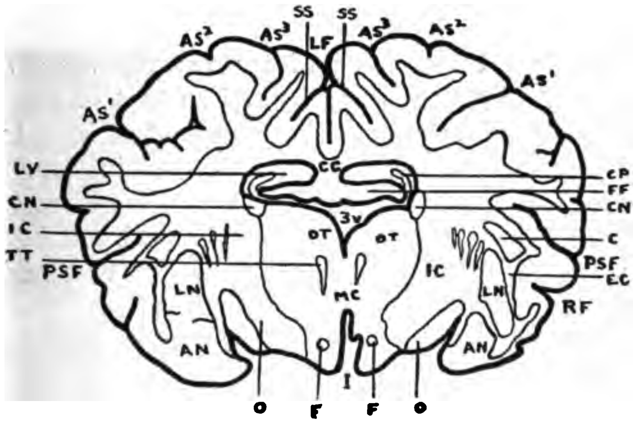


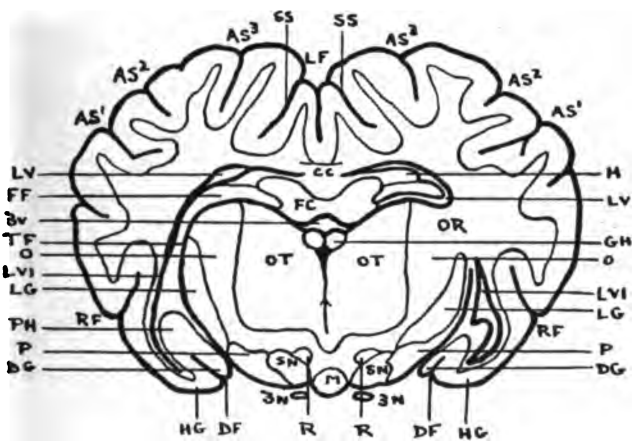


FIG. 15.—TRANSVERSE SECTIONS 3 AND 4

AS¹, ², ³, arcuate sulci
AN, amygdaloid nucleus
CC, corpus callosum
CN, caudate nucleus
CP, choroid plexus
DF, dentate fissure
DG, dentate gyrus
F, fornix
FF, fimbria
FC, fasciola cineria
GH, ganglia of the habenulæ
H, hippocampus
HG, hippocampal gyrus
I, infundibulum
IC, internal capsule
LF, longitudinal fissure
LG, lateral geniculate body
LN, lenticular nucleus
LV, body of the lateral ventricle
LVI, inferior horn of lateral ventricle
M, mammillary bodies
MC, middle commissure
O, optic tract
OR, optic radiation
OT, optic thalamus
P, pyramid
PH, pes hippocampi,
PSF, posterior ramus of Sylvian fissure
R, red nucleus
RF, rhinal fissure
SN, substantia nigra
SS, splenial sulcus
TF, transverse fissure
TT, tænia thalami
3 v, 3d ventricle
3 n, 3d cranial nerve

most important components of the nervous system, and while its careful study is as essential as that of any other portion of the brain, it is beyond the scope of an introductory treatise to attempt more than a brief examination. Only the fundamental tracts and ganglia will therefore be described, more with the purpose of establishing a basis for further study than to present a comprehensive description of this region.

A section made through the superior corpora quadrigemina cuts the cerebrum at the junction of the occipital and parietal lobes, the hemispheres being now entirely separated by the posterior end of the longitudinal fissure. The knife passes through the length of the inferior horn of the lateral ventricle and the gray and white matter of the hippocampus on its floor. The vessels in the pia mater of the velum interpositum are seen passing forward in the transverse fissure intervening between the hemispheres above and the midbrain below. The superior quadrigemina appear as two rounded eminences separated by a shallow cleft, at the bottom of which the posterior commissure passes between them, connecting them with each other and, continuing downward, with the fibers of the tegmentum below. Under this is the aqueduct of Sylvius, the canal of the midbrain, furnishing a communication between the third and fourth ventricles; it is surrounded with gray matter throughout its length.

Ventral to the central gray matter, is the general region known as the tegmentum, composed, for the greater part, of sensory nerves on their way to the higher centers, and the ganglia distributed along their course. This portion of the brain stem has a characteristic appearance throughout its length, from the scattered nuclei and irregularly disposed fibers of which it is composed, known as the reticular[1]

[1] Lat. *reticulum*, a little net.

formation. An important fiber tract of the tegmentum is the posterior [mesial] longitudinal bundle, made up of fibers forming relays up and down the cord between the nuclei of this and more posterior regions, especially between the cranial nerve nuclei, thus affording, for example, coördination between those nerves which control the eye movements. Some of its fibers are also undoubtedly concerned in the formation of the posterior commissure. It is to be found on either side of the middle line in the ventral border of the central gray matter.

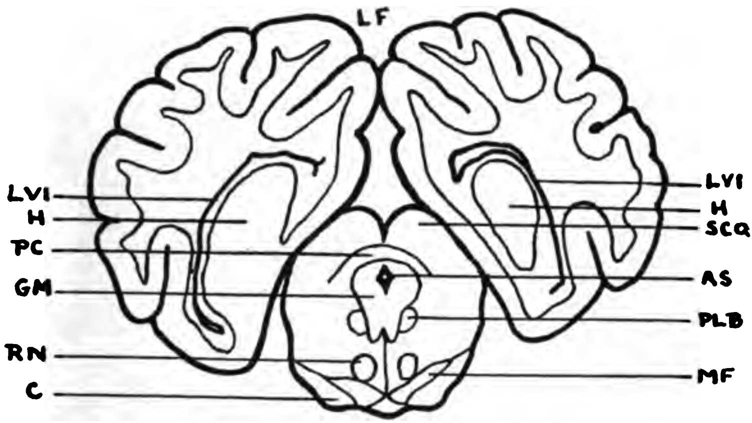
Just above the posterior bundle lie the nuclei which make up the deep origin of the third nerve, sending their fibers downward to emerge on the ventral surface of the crura. On their way these fibers pass through the red nuclei, which are at their largest in this region; these we have seen are largely associated with the fibers of the superior cerebellar peduncles, which decussate just posterior to the plane of the section. Below and laterally to these are seen the large white bundles of the mesial fillet or lemniscus. These are the general sensory fibers, ascending from the nuclei in the medulla, which have relayed from the cord and sensory cranial nerves on their way to the thalami, where they relay again and pass to the cortex. The crusta lies below each mesial fillet, separated from it (and the entire tegmentum) by the substantia nigra. The crustæ, as has already been observed, are composed entirely of descending motor fibers, of which the pyramidal tract occupies the greater part.

The next section passes through the center of the pons and the tips of the occipital lobes, and cuts off a small fragment from the anterior extremity of the cerebellum. Below the cerebellum, the knife passes through the inferior quadrigeminal bodies and just in front of the anterior medullary

velum, which stretches between them on its way back to the cerebellum. The velum is seen to form the anterior roof of the fourth ventricle, and the inferior quadrigemina its sides; the floor of the ventricle is made up mesially of gray matter, and laterally by the fibers on the inner side of the superior cerebellar peduncles, which extend from beneath the inferior quadrigemina backward to the cerebellum. In this region, beneath the inferior quadrigemina, lie the nuclei of origin of the fourth cranial nerves. Their fibers pass backward, decussate in the velum and emerge dorsally just above it; the knife has passed through the decussation.

The pons is divided into two lateral parts by a median raphe,[1] and into two horizontal halves, the ventral corresponding to the crustæ, and the dorsal to the tegmentum, of the midbrain. The ventral portion is the larger in man, but the smaller in the sheep; it is composed, in addition to the motor fibers entering it from above, of transverse fibers which pass into it and out of it from the cerebellum through the middle peduncles, and of the pontal nuclei. The latter serve as a relay for the transverse fibers, which enclose the longitudinal motor fibers in an outer and an inner layer. The superficial transverse fibers terminate in the ganglia of the same side, the deep transverse fibers in those of the opposite side. Many of the deep fibers also pass from the acoustic areas to the lateral fillets in the tegmentum, whence they pass forward to the inferior quadrigemina and the higher centers of hearing, as mentioned in the previous chapter. The pontal nuclei also form relays for the motor fibers situated in the outer and inner fifth of the crustæ, *i.e.* the fibers from the temporal and frontal cortices, respectively, the pyramidal tracts alone occupying the middle three-fifths of the crustæ, and continuing intact through the pons to the lower centers.

[1] Gr. *rhaphē*, a suture.



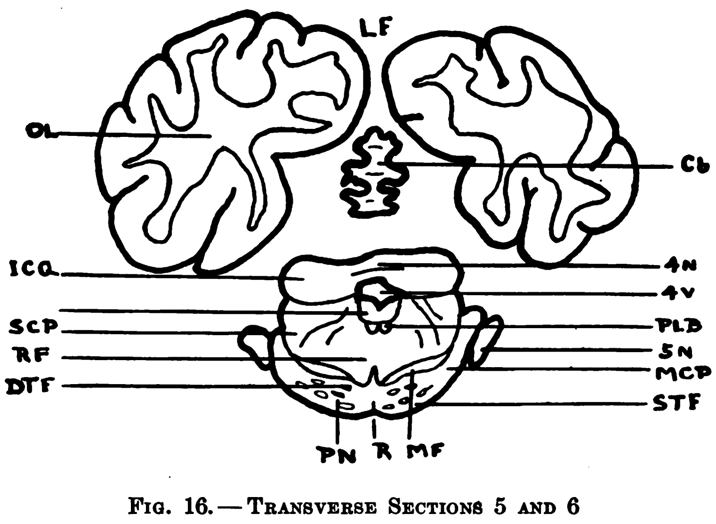


FIG. 16.—TRANSVERSE SECTIONS 5 AND 6

AS, aqueduct of Sylvius
Cb, cerebellum
CT, crusta
DTF, deep transverse fibers of pons
GM, gray matter
H, hippocampus
ICQ, inferior corpora quadrigemina
I.F, longitudinal fissure
LVI, inferior horn of lateral ventricle
MCP, middle cerebellar peduncle
MF, mesial fillet
OL, occipital lobe
PC, posterior commissure
PLB, posterior longitudinal bundle
PN, pontal nuclei
R, raphe
RF, reticular formation
RN, red nucleus
SCP, superior cerebellar peduncles
SCQ, superior corpora quadrigemina
STF, superficial transverse fibers of pons
4 n, 4th cranial nerve (decussation)
4 v, 4th ventricle
5 n, 5th cranial nerve

The tegmental part of the crura passes through the pons almost intact, but the substantia nigra below it is lost. The center of this dorsal portion of the pons is of reticular formation, *i.e.* gray and white matter intermixed, its fibers running for the most part longitudinally forward, and forming a series of short ascending (sensory) pathways from the nuclei in the medulla to the higher centers. The mesial fillet passes forward on either side between the pyramidal fibers and the reticular formation; and the posterior longitudinal bundles are seen close together under the gray matter of the ventricle floor. Laterally to the reticular formation are the superior cerebellar peduncles and the lateral fillets, already described. Laterally to the middle cerebellar peduncles are seen the cut fibers of the fifth nerve, its superficial and deep origin being posterior to the plane of this section.

The last section has been made .through the posterior portion of the trapezoid body. It passes through the middle of the fourth ventricle and near the middle of the cerebellum, behind the cerebral hemispheres. The arrangement of the white and gray matter of the cerebellum is well shown, the superior vermis appearing above, and the inferior below, protruding into and forming the roof of this portion of the ventricle. On either side, the fibers making up the middle peduncles may be seen passing forward and downward out of the cerebellum. The section shows in the center the reticular formation and raphe, the former made up largely of scattered nuclei and sensory fibers ascending from the medulla and cord behind. The posterior longitudinal bundle is formed dorsally by a collection of the fibers from nuclei in this region. The lateral and ventral borders of the section are white, representing the afferent and efferent fibers of the inferior cerebellar peduncles ascend-

ing from or descending into the cord, and the cut fibers of the pyramidal tract, respectively.

Near the middle line, above the pyramids, the mesial fillets are cut across; behind the plane of the section, their fibers arise from the cell bodies in the gracile and cuneate nuclei, ganglia found at the forward extremities of the large dorsal gracile and cuneate tracts, passing up the cord. From these nuclei, fibers pass ventrally and mesially across the middle line and pass upward as the mesial fillet of the opposite side. These fibers are known at their point of crossing as the internal arcuate fibers, which here make up the sensory decussation [decussation of the lemnisci]. The motor fibers forming the ventral pyramids also decussate, their greater portion passing dorsally and laterally to form the crossed pyramidal tract of the cord, a smaller number remaining in the original location, as the direct pyramidal tract of the cord. This is the pyramidal decussation, occurring at a more posterior level than the sensory, near the junction of the medulla oblongata and spinal cord; in man, the decussating fibers may be seen on the ventral aspect.

Just behind the trapezoid body, and laterally to the pyramids, the olives appear; in man, they are seen on cross section to consist of a wrinkled capsule of gray matter, with a white center composed of fibers partly from the gracile and cuneate nuclei but mostly from the cerebellum via the opposite inferior cerebellar peduncles. The latter also receive fibers from the gracile and cuneate nuclei by the anterior external arcuate fibers, running around the medulla oblongata from the ventral surface (a continuation of the internal arcuate fibers, and so from the nuclei of the opposite side), and by the posterior external arcuate fibers, passing outward dorsally from the nuclei of the same side.

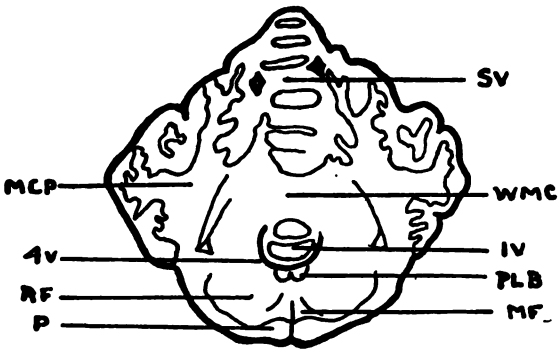
The deep origins of all the cranial nerves behind the fourth

are to be found in nuclei situated in the pons and medulla, all beneath or very near the floor of the fourth ventricle. For the exact location and connections of these nuclei (as well as other points which have been slighted in this chapter) the student is referred to more complete texts. It is sufficient to say in this connection that all these nuclei receive or give off fibers which are continuous with or are grouped with those of the larger motor and sensory bundles already considered, and that in every case these fibers cross the middle line before reaching their superficial origin. It must also be observed that practically all the motor and sensory fibers decussate either at higher or lower levels before reaching their destination, so that the higher centers of one side innervate the body on the opposite side; and that while all the sensory and many of the motor fibers relay throughout their course (*i.e.* their path is made up of more than one neurone), the general motor fibers of the pyramidal tract form no relays in the brain, but each passes to the cord as the axone of a single cortical cell.

DIRECTIONS: The sections illustrated and described in this chapter may be made as follows. The first horizontal section is started through the cerebellum at the level of the dorsal surface of the superior corpora quadrigemina (found by separating the cerebellum from the cerebral hemispheres until the quadrigemina are exposed), and then continuing the cut horizontally forward through the hemispheres, keeping the knife parallel to the base of the brain. The second horizontal section is made one-half inch below the preceding, through the bottom portion of the inferior quadrigemina, and is made parallel to the first.

The incisions for the transverse sections should be begun on the ventral surface; the first, a quarter of an inch anterior to the optic chiasm, the second, through the anterior part of the chiasm, the third, through the infundibulum, the fourth, at the posterior end of the mammillary body, the fifth, at the anterior border of the pons, the sixth, through the middle of the pons, and the seventh, at the posterior border of the trapezoid body.

It is possible to use for these sections the brain which has been cut for the median sagittal section, using one-half for the transverse and the other



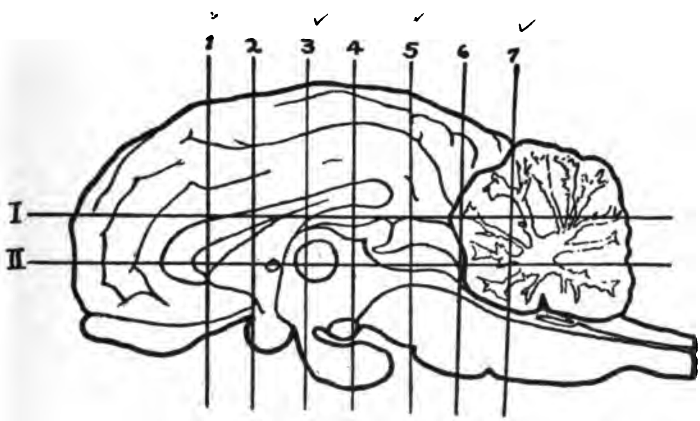


Fig. 17. — Transverse Section 7

IV, inferior vermis
MCP, middle cerebellar peduncle
MF, mesial fillet
P, pyramid
PLB, posterior longitudinal bundle
RF, reticular formation
WMC, white matter of cerebellum
SV, superior vermis
4 v, 4th ventricle

KEY TO POSITION OF SECTIONS

I, II, horizontal sections
1–7, transverse sections

for the horizontal sections, although separate brains are preferable. The accompanying diagram (Fig. 17) makes the position of these sections clear and should be referred to in studying each section. Sections intermediate to the ones employed in this chapter will be found equally instructive and should be made in addition to those directed. Compare contiguous sections, tracing the structures through them, and dissecting them carefully after a drawing of each surface has been made.

X

SUMMARY

The student who has completed the dissection of the sheep's brain should now be familiar with its gross anatomy, with the relations of the more fundamental of its intricate structures, and with the rather complex and confusing nomenclature associated with it. He should be ready, therefore, to appreciate a general summary of nervous function, especially in its more particular application to cerebral physiology.

As the anatomical unit of the nervous system is the neurone, so its physiological unit is the simple reflex. All varieties and complexities of nervous structure can be described and explained as more less intricate combinations of reflex arcs. By the latter is understood a mechanism consisting of two, three, or more neurones, of which one, at least, must be afferent, and one efferent, so related that an incoming (or sensory) impulse "discharges," so to speak, an appropriate outgoing (usually motor) impulse, in response. In other words, the reflex arc is such a combination of neurones as to afford for the animal, through its nervous equipment, direct or indirect reaction to stimuli acting upon it.

In Chapter I, it was observed that the unicellular amœba reacts to its environment, though composed of undifferentiated protoplasm; that even this simplest animal acts reflexly. We saw, as we ascended the invertebrate scale, the more and more perfect adaptation of structure to reflex action, by the specialization of a portion of the body cells

for nervous function alone. Certain cells on the periphery become more irritable than the others, and lose their other functions; this rudimentary sensory epithelium is the precursor of the sense organs of the higher forms. Other cells become specialized as conductors; these are the rudimentary nerves, carrying impulses inward from the superficial sensory cells and outward to the muscles, and also, as a later development, forming association fibers of varying lengths between the other two, thus furnishing immensely greater complexity and usefulness to the reflex arc. The conduction, which is diffuse and universal in cœlenterates, as the medusa, becomes systematized in the centralized nervous apparatus of the earthworms; the connections are more precise, because made through definite ganglionic centers, and are quicker between distant parts, due to the presence of longer nerve strands. In the crustaceans and other higher invertebrates, the increased size and complexity of the ganglion of the anterior segment, and the association with it of highly specialized sense organs, such as the eye, which react to stimuli at a distance, give to these animals still more exact and varied reflex activities, and greater facilities for complicated responses to the world about them.

The addition of important accessory organs to the cerebral ganglion, or brain, is the characteristic feature of the advance made by the vertebrates in the evolution of the nervous system. The great centers and long fiber tracts of these new accessories (corresponding to the connections and limbs of the reflex arcs), by providing for these animals greater modifiability and adaptability to environment, come to overgrow, and indeed overrule, the simpler systems of the invertebrates. The diversities of structure seen in the different vertebrate brains are largely dependent upon the sensory equipment of each animal, as those parts of the brain most intimately connected with the dominating sense

organs are themselves the most highly developed, and the fiber systems leading to and from these parts are the largest and longest, and are the paths utilized by those reflexes most important in regulating the animal's behavior.

Thus the great dependence of the vertebrates upon the sense of sight gives to the optic centers great predominance. The optic lobes, being the highest visual centers possessed by all vertebrates below the mammals, are therefore enormously developed, and are quite possibly, for these animals, the dominant part of the whole nervous system; they send impulses out to all parts of the body, through the efferent limbs of reflex arcs whose afferent limbs originate for the greater part in the optic tracts. Likewise the early forebrain is the primary center for smell, and its ganglionic portion, the corpus striatum, is probably entirely concerned in this function in the lower vertebrates. Indeed, the whole pallium is without doubt the higher center for smell and the allied oral senses in vertebrates below the birds, in whom connections between the pallial cortex and a second region, the optic lobes, are first seen.

This early forebrain system for olfaction, consisting of the olfactory tracts, the corpus striatum, the fornix, certain parts of the interbrain, and all the pallium to be found in these vertebrates, is often termed the "archipallium,"[1] to distinguish it from the "neopallium,"[2] that additional part of the cerebral cortex and its connections developed in the birds and mammals. In the latter, the archipallium is almost entirely buried beneath the tremendous growth of the neopallium. This new cortex spreads upward and over the old in all directions, stretching out the hippocampus and fornix (the old olfactory cortex and its fiber connections to the interbrain), along its inner edge. The function of

[1] Gr. *archē* first, and Lat. *pallium*, mantle.
[2] Gr. *neos* new, and Lat. *pallium*, mantle.

the archipallium probably remains unchanged, but its importance as a higher center is greatly diminished in those animals possessing a well-developed cerebral cortex (neopallium), which assumes charge of all the higher functions; in man, the archipallium and its connections are, together with the sense of smell, very rudimentary.

The mammalian brain is distinguished by the development of the neopallium, which constitutes by far the greater part of the cerebral hemispheres. Its increase in size is accompanied by increased growth and complexity in the cerebral cortex, with a corresponding predominance of the fiber systems leading to and from it, and interconnecting its many regions, making up the vast white medulla of its hemispheres. The ganglionic centers of the earlier systems, the thalamus, the optic lobes, the geniculates, and the brain stem nuclei, now become connected with the cerebral gray matter, the primary sensory tracts which ended in these centers now finding their terminations beyond them in the cortex. The influence exerted by the cerebrum over the lower centers varies with the vertebrate class, being much greater in the mammals than in other vertebrates, and greatest of all in man. This supremacy of the cortex is largely due to the development of its long fiber systems, which, both afferent and efferent, extend farther and farther back, and assume more and more control over the brain stem and cord.

One after another, the senses find representation in the cortex; the olfactory and oral senses of the lower vertebrates are followed by vision in the birds, audition, the tactile and organic senses being added in the mammals. Between these sense centers, as well as with the lower levels, connections are formed, and the scope of sensory association and consequent behavior is correspondingly increased. The specialization of one definite area of the

cortex as the origin of the great motor pyramidal tract, whose fibers overgrow those of the earlier sensory systems, furnishes for the cerebrum voluntary control over the lower mechanisms, and so over the entire body, in accordance with the impulses reaching the motor area from the other parts of the cortex. In the human brain, the great areas of cortex surrounding the primary centers seem to be concerned in the utilization of the sensory material furnished by the receptive apparatus of the body, and by the sense organs, and, in general, the cortex may be considered as the anatomical basis for the highest psychical functions; unquestionably, general intelligence — the ability to learn, and all complex mental performance — varies with, and depends upon, the development of this portion of the mammalian brain.

The action of the cerebrum is accomplished, as in all nervous tissue, by the conduction of impulses between masses of gray matter (cortex and nuclei) via the nerve fibers, or fiber systems. It is obvious, therefore, that there is no better means of investigating the function of the whole brain, or its separate centers, than by tracing the course of the tracts connecting its various parts; as most of the research along these lines has been performed on the brains of the primates, especially man, a description of the tracts, centers and relations in the human brain will be largely followed here. The vast and intricate network of fibers making up the medulla of the cerebral hemispheres may be resolved into three great classes: projection fibers, which grow into the cerebrum from the interbrain below and are distributed to the cortex, or which originate in the cortex and pass downward out of the cerebrum into the midbrain, including, therefore, all the fibers making up the corona radiata; association fibers, both short and long, connecting different areas at varying distances in the same hemispheres; and commis-

sural fibers, which originate in one hemisphere and pass across the middle line to terminate in the other.

While projection fibers may be traced to all parts of the cortex, they are most numerous leading from that part just anterior and posterior to the fissure of Rolando, from the region of the calcarine fissure in the occipital lobe, and from the superior temporal gyrus. This suggestion of a cortical localization of function has been borne out by many lines of investigation, and it can be definitely stated that, in man, the precentral gyrus of the frontal lobe is the origin of the motor tract which controls movements of all the voluntary muscles, and that the area just behind this, the postcentral gyrus, is the receiving station for sensation from the body and skin. In both these areas, the lower limbs find representation in the cortex nearest the longitudinal fissure, below this the trunk, then the arms, the neck and the face, whose cortex almost reaches the fissure of Sylvius. That portion of the cortex which constitutes the highest center for sight has likewise been located; this visual area is on the mesial side of each occipital lobe, surrounding the calcarine fissure. Similarly, the posterior two thirds of the superior temporal gyrus has been found to be the primary auditory center, the receiving and distributing station for impulses coming from the ear. Very similar location for all these centers have been found in the other primates, and, indeed, in some of the other mammals.

Of the projection fibers, there are two so-called "direct" paths. One of these is the direct pyramidal, made up of the axones of cells in the motor area, or cortex, of the precentral gyrus. Its fibers pass downward in the corona radiata, occupy the middle region of the internal capsule, and then, dipping under the thalamus, constitute the middle three-fifths of each crusta of the crura (midbrain) and the anterior longitudinal fibers of the pons. Those of its fibers which

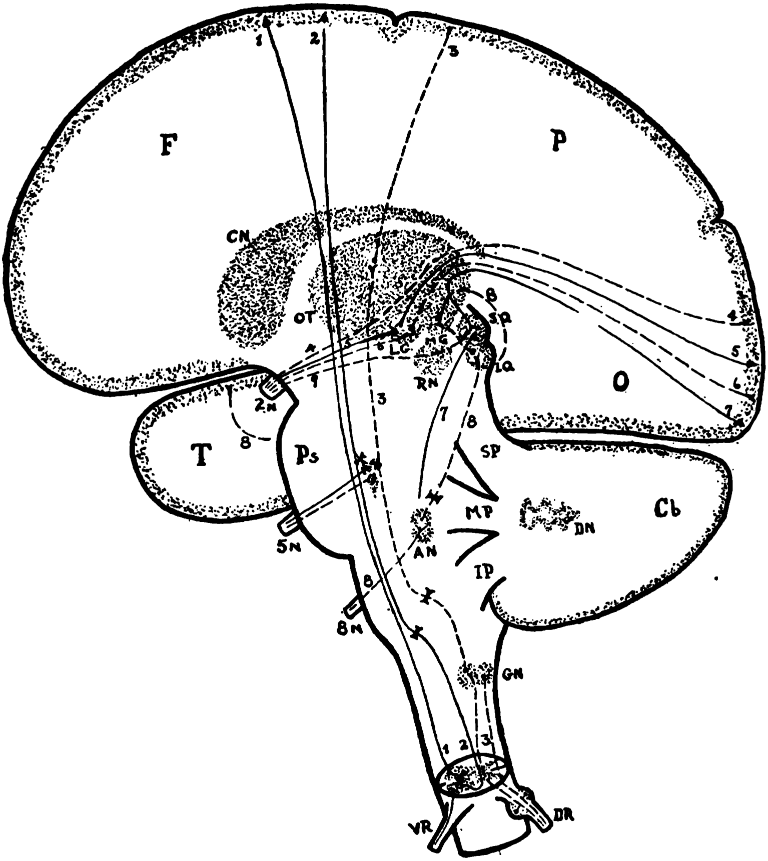


FIG. 18.—SCHEME OF NEURONES MAKING UP THE PRINCIPAL DIRECT PROJECTION PATHWAYS

efferent fibers ——— **afferent fibers** - - - - - - -

AN, cochlear nuclei
Cb, cerebellum
CN, caudate nucleus
DN, dentate nucleus
DR, dorsal root of spinal nerve
F, frontal lobe
GN, gracile and cuneate nuclei
IP, inferior cerebellar peduncles
IQ, inferior corpora quadrigemina
LG, lateral geniculate body
MG, median geniculate body
MP, middle cerebellar peduncle
O, occipital lobe
OT, optic thalamus
P, parietal lobe
Ps, pons
RN, red nucleus
SP, superior cerebellar peduncles
SQ, superior corpora quadrigemina
T, temporal lobe
VR, ventral root of spinal nerve
2 n, 2d cranial nerve
5 n, 5th cranial nerve
8 n, 8th cranial nerve
---I--- indicates decussation

1. direct pyramidal tract
2. crossed pyramidal tract
3. direct sensory tract
4. direct optic tract, retina to cortex
5. direct optic tract, cortex to eye
6. optic pathway, retina to cortex via lateral geniculate body
7. optic pathway, cortex to cranial nerve nuclei, via superior quadrigemina and posterior longitudinal bundle
8. auditory path
9. optic fibers, retina to superior quadrigemina, for direct reflexes via posterior longitudinal bundle

relay to the cerebral nerves leave the tract as it descends from the midbrain, and pass to the nuclei of all except the olfactory and optic, crossing the middle line for all nuclei except that of the fourth. The greater proportion of the fibers continue through the pons, however, and form the pyramids of the medulla oblongata (whence the name of the tract). At the lowest level of the pyramids, the majority of the fibers cross the medulla in the pyramidal decussation, and continue downward on the sides of the spinal cord, while the smaller number descend on the same side of the cord, crossing it at successively lower levels. In the cord, these axones, which have continued uninterrupted from the cortex, and are, therefore, among the longest in the body, relay with a second set of neurones whose axones pass directly to the muscles.

The other direct system of projection fibers is that which carries impulses of general sensation from the tactile endings in the skin and muscles, to the somæsthetic[1] area in the postcentral cortex. These fibers, which lead directly from the sensory endings, pass up the dorsal and lateral columns of the spinal cord and find endings in the region of the gracile and cuneate nuclei just below the medulla. Axones of cell bodies in these nuclei carry the impulses upward through the medulla, where they cross the middle line in the sensory decussation, and then via the mesial fillet through the reticular formation of the pons and midbrain to the lateral nucleus of the thalamus. Here they relay for a second time, and, continuing upward in the posterior limb of the internal capsule (mingling with the motor fibers) and through the corona radiata, terminate in the cortex. In the brain stem the tract is joined by crossed fibers from the terminal nuclei of the fifth, eighth, ninth, and tenth cranial nerves. The afferent fibers concerned with the conscious

[1] Gr. *sōma*, body, and *aisthēsis*, sensation; body sense.

sensations of pain, temperature, and touch localization, probably reach the gracile and cuneate nuclei via the lateral columns of the cord, after decussating, and do not ascend in the dorsal columns. It is seen that the general sensory path exhibits the same crossed innervation as the general motor, that is, the cortex of the right cerebral hemisphere receives impulses from, and sends impulses to, the left side of the body, and *vice versa*; but that the sensory path consists of at least three neurones (and usually more) between the cortex and periphery, while the voluntary motor path requires but two neurones for its completion.

Of the other pathways for impulses carried by the projection fibers between the cerebrum and the body, those which pass through, or rather relay in, the cerebellum, and are therefore "indirect," are the most important. The cerebellum is formed from the roof of the hindbrain, and becomes a highly developed organ in those vertebrates possessing great powers of locomotion, as the bony fishes, the birds, and most mammals, especially man. Its intimate connection with the vestibular branch of the eighth nerve, and the similarity between the disturbances caused by its injury and those from injury to this nerve (disturbances of equilibrium), would make the cerebellum seem but an expansion of the nerve center; but this organ also communicates with the muscles, as well as other parts of the body, by a rich system of both afferent and efferent fibers, and its function is evidently to coördinate movements and maintain muscle tone, as well as to govern equilibrium. While the action of the cerebellum is probably unattended with consciousness, it receives a large mass of fibers from the cerebrum, and undoubtedly forms an important way station for impulses passing from the central cortex to the muscles, and directing conscious movement.

This pathway from the cerebrum to the cerebellum, thence to the muscles, originates in the frontal lobe, anterior to the

pyramidal cortex, and is known as the fronto-ponto-cerebellar tract; another similar tract, originating in the temporal cortex, is known as the temporo-ponto-cerebellar. The fibers of these tracts pass downward through the corona radiata to the pons, the frontal fibers occupying the frontal part of the internal capsule and the mesial fifth of each crusta, the temporal fibers the posterior end of the capsule and the lateral fifth of each crusta. They relay in the pontine nuclei on the same side (and some, also, in the cranial nerve nuclei), thence they pass by the opposite middle cerebellar peduncle to the cerebellar cortex, particularly the cortex of the lateral hemispheres. From here they are relayed downward through the inferior cerebellar peduncles to the cord, or upward to the red nuclei, thence down to those neurones of the cord whose fibers pass directly to the muscles. Another, somewhat similar, efferent pathway proceeds from the cortex to the thalamus (or, in some cases, the corpus striatum), relays from there to the red nucleus, from which fibers proceed backward, decussating, to the cerebellar cortex via the superior cerebellar peduncles. From here the path is relayed to the dentate nucleus, thence down the cord by the anterior descending cerebello-spinal tract.

Of the indirect sensory routes, making use of afferent projection fibers, nearly all have the same path from the cerebellum to the cerebral cortex, but they reach the former in different ways. One path leads from the gracile and cuneate nuclei to the inferior cerebellar peduncles via the external arcuate fibers; another directly up the cord to these peduncles, thence to the cortex of the superior vermis; while yet a third, which carries impulses from the cutaneous sensory endings, passes up through the lateral portion of the reticular formation of the medulla and pons nearly to the corpora quadrigemina, where some of the fibers continue on to the thalamus, but others turn abruptly backward, and

reach the superior vermis through the superior cerebellar peduncles. From the cortex of the vermis all have the same path: to the dentate nucleus, opposite red nucleus via the superior cerebellar peduncles, thalamus, and cortex of the somæsthetic area.

Several other routes taken by the cortical projection fibers to carry impulses between the cerebral cortex and the body have been traced out, and there are undoubtedly many others which are not known, but none are as important as the ones outlined above. A rather well-known efferent tract originating in the cortex relays in the thalamus or corpus striatum, thence passes to the red nucleus, and from here decussates and passes downward in the lateral fillet through the reticular formation of the midbrain and pons, to the cord. Fibers have also been demonstrated which carry impulses downward from the pontine nuclei to the cord, their origin (presumably in the cerebral cortex) not being known. There are also many short fiber paths, both afferent and efferent (*e.g.* posterior longitudinal bundle) which by numerous relays furnish communication between the cortex and cord, and afford reflexes of varying complexity between the incoming and outgoing impulses. The reflex action, indeed, of the whole system must not be lost sight of, and the above sketch of the most important pathways through the tangled mass of fibers making up the interior of the human brain but suggests the tremendous possibilities for intricate connections between its multitude of organs and systems.

A large proportion of the projection fibers have not been mentioned, viz. those concerned in completing the great pathways between the special sense organs and the cortex. The optic path begins with the nerve fibers from the retinæ, those from the same half of each retina forming the optic tract of that side by means of the crossing at the chiasm (the nasal halves decussate). The optic tracts end in the lateral

geniculates and the pulvinar of each thalamus, some fibers also passing to the superior corpora quadrigemina. These bodies, which were so highly developed in the birds and some of the other vertebrates, are small in man, and utilized for lower reflexes only (occular and pupillary). Relaying in the thalamus and lateral geniculate, each optic path is continued on by a large group of fibers known as the optic radiation, occupying a position at the posterior end of the internal capsule, and ending in the half-visual center in each occipital lobe.

The auditory nerve is double, its cochlear division being concerned with hearing, its vestibular division with equilibrium. The cochlear branch ends in the cochlear nuclei in the medulla, from which the more anterior fibers pass across the middle line to the opposite olive, forming the trapezoid body, and join the posterior fibers, which have formed the acoustic striæ in the floor of the fourth ventricle. From here they pass up the lateral fillet to the inferior quadrigeminal bodies, and to the median geniculates, via the brachia of the inferior quadrigemina, from which a new set of fibers completes the pathway to the temporal cortex, previously described. The vestibular branch likewise terminates in nuclei in the medulla oblongata, from which the impulses pass via the external arcuate fibers and the inferior cerebellar peduncles to the cerebellar cortex. From here the probable path to the temporal cortex is that of the other cerebello-cerebral fibers, via the superior cerebellar peduncles, crossing into the red nucleus, then to the thalamus and cortex (via the temporal radiation). There is also a direct path from the medulla, following that of the (direct) general sensory fibers to the thalamus, thence relaying to the temporal cortex.

The olfactory and gustatory systems may also be classed under projection pathways, as their fibers pass into the cere-

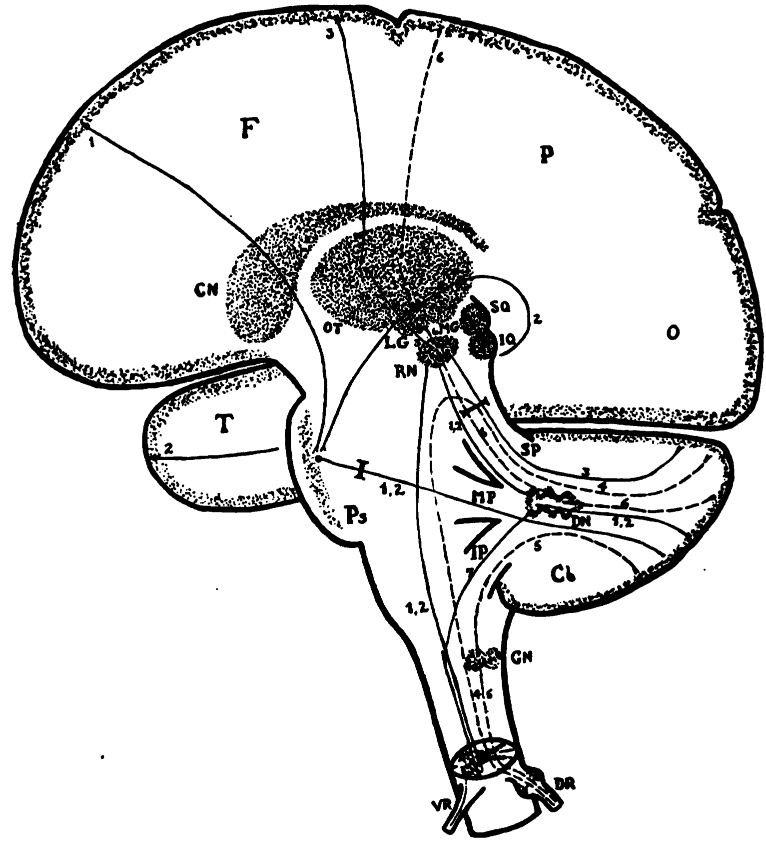


Fig. 19.—Scheme of Neurones Making up the Principal Indirect Projection Pathways

efferent fibers ———	afferent fibers -------
Cb, cerebellum	O, occipital lobe
CN, caudate nucleus	OT, optic thalamus
DN, dentate nucleus	P, parietal lobe
DR, dorsal root of spinal nerve	Ps, pons
F, frontal lobe	RN, red nucleus
GN, gracile and cuneate nuclei	SP, superior cerebellar peduncles
IP, inferior cerebellar peduncles	SQ, superior corpora quadrigemina
IQ, inferior corpora quadrigemina	T, temporal lobe
LG, lateral geniculate body	VR, ventral root of spinal nerve
MG, median geniculate body	2 n, 2d cranial nerve
MP, middle cerebellar peduncle	5 n, 5th cranial nerve
	8 n, 8th cranial nerve
	--I-- indicates decussation

1 and 2. fronto- and temporo-ponto-cerebellar tracts, via pons, cerebellum, red nucleus, and cerebro-spinal tract.
3. motor tract to cerebellum via red nucleus and superior cerebellar peduncles
4. sensory fibers turning back into cerebellum via superior peduncles
5. sensory fibers to cerebellum via inferior peduncles
6. general pathway from cerebellar to cerebral cortex, via dentate and red nuclei, and thalamus
7. anterior cerebello-spinal tract, dentate nucleus to cord via inferior peduncles

bral hemispheres from below, and terminate in the cortex. The olfactory tract, from the nose and bulb, divides into three roots; their terminations in the sheep have been already noted, and their endings in the human brain will be given here. The mesial root ends in Broca's area [par-olfactory area], the triangle [trigone], the subcallosal gyrus, and, through this, the gyrus cinguli, from which, via the fornix and the cingulum, fibers reach the hippocampal uncus. From the internal root fibers pass to the triangle, the anterior perforated space, and thence to the uncus, similarly to the fibers of the mesial root. In the internal root there are also fibers which pass directly to the opposite hippocampal lobe via the anterior commissure. The fibers of the lateral root pass to the uncus directly. These terminations, especially the uncus, may be taken as the known location of the olfactory cortex in man, corresponding largely to the archi-pallium, and being relatively rudimentary, as previously explained.

The fibers conveying taste impulses enter the medulla by the ninth nerve, and the intermediate part of the seventh and eighth, and end in nuclei, which relay the path to the opposite thalamus, via the reticular formation. From each thalamus the path leads through the internal capsule to the cortex of the fusiform [1] gyrus, or to the gyrus cinguli, but the precise location of the taste area of the cortex is still in some doubt. From this review of the special sensory systems it will be noted that all these afferent fibers ultimately reach the cortex of the opposite hemisphere, in the same way that the general motor and sensory fibers cross, with the exception of the olfactory fibers which remain on the same side (except those in the anterior commissure) and, as far as is known, are the only paths which do. It may be added, before leaving this subject, that afferent fibers have been

[1] Lat. *fusus*, spindle, and *forma*, shape.

traced from the visual, auditory, and olfactory cortices to the lower centers, following largely the afferent paths to the cortex, and are probably concerned in adjusting the sense organs in direct response to the special sensory impulses.

While the projection fibers undoubtedly constitute the most fundamental conduction system of the mammalian brain, the importance of the association fibers in the higher forms especially, must not be underestimated. This system makes up by far the greatest portion of the medulla of the hemispheres, and is, if anything, more dependent for its bulk upon the development of the cortex than the projection systems, since it is only in those mammals with extensive cortices that it forms such a significant constituent of the cerebrum. The association fibers may be classified as short and long; the intricate network of the former may be found for the most part just below the cortex, its fibers joining neighboring areas of cortex and emerging from the longer tracts at various intervals. The latter may be more easily traced, however, and of these the following tracts are, in each hemisphere, the most distinguishable: one between the temporal and occipital lobes; one between the temporal and parietal; a third between the temporal and frontal; a fourth extending the whole length of the cerebrum from the frontal to the occipital lobe; and a fifth curving the length of the limbic lobe (the cingulum). The commissural fibers, uniting the two hemispheres, have a distribution almost as general as that of the association tracts and are most numerous in the same animals, especially man, whose greatest commissural system, the corpus callosum, is much more extensively developed than in other mammalian brains.

The function of these intrinsic connections is best understood by an examination of the areas which they bring into communication. For not only do the association fibers form bridges between the definitely localized sensory and motor

areas, already considered, but some also pass from these centers to the surrounding cortex, while others, entirely independent of the primary centers, join together portions of these outlying areas. These secondary regions are often called "silent areas," because silent to stimulation, but are, perhaps, better known as "association areas" from their associated relation to the primary centers (from an anatomical rather than a psychological standpoint). In the human brain, these areas are, both absolutely and relatively, the largest, and occupy by far the greater portion of the cortex, consisting mostly of four great regions; all of the frontal lobe but its most posterior portion, the greater part of the temporal lobe, the posterior two-thirds of the parietal lobe, and the island of Reil.

While knowledge of the functions of the silent areas is indefinite and far from complete, we may be reasonably sure of the action of certain parts of them. The cortex immediately surrounding each of the localized sense centers is richly connected to it by short association fibers, and it is practically certain that this cortex is concerned with the utilization of the sensory data peculiar to that center. Injuries to the immediate neighborhood of the receiving station for each sense cause the loss or disturbance of the closely related psychical processes, especially the ability to recall or use images in terms of that sense. Probably the most universally recognized of these outlying regions is a considerable area of the parietal cortex posterior to the general sensory area, which is held to be the center for man's stereognostic or "sight-feel" sense, its function being the correlation of data from the tactile and muscular endings with the visual data from the eye.

As to the remainder of the cortex, even less is definitely known. The use of articulate language is apparently closely associated with two areas in the left hemisphere, the cortex

of the left inferior frontal gyrus, and the cortex of the temporal lobe just posterior to the primary auditory center. The former seems to be concerned in combining the elementary movements of the organs of speech into spoken words, and the latter to be closely related to the sensory processes of speech, in terms of auditory images. Likewise, a center for writing has been claimed in the middle frontal gyrus of the left hemisphere, close to the motor area for the hand; this is not conclusively proven, but there is considerable evidence to support it, and to prove, further, that this region is of special importance in all learned and skilled movements. This predominance of the left hemisphere in relation to acts of skill and their associated psychological processes has been attributed to man's general right-handedness. Whether or not this is true, the fact remains that very little is known of the functions of the right hemisphere beyond the action of its primary centers, while the left is apparently the seat of the motor functions and intellectual processes concerned with speech and other attainments peculiar to man.

The frontal lobes have long been considered man's special intellectual centers, or, at least, to be concerned with his "character" or "personality." All evidence of value from animal experimentation points to these lobes, particularly the left, as being concerned in the acquisition of new acts, and this only; moreover, many injuries to the frontal lobes in man have produced no symptoms whatsoever. It is more probable that man's intellectual supremacy depends upon the superior development of his whole cerebrum, particularly the great association areas, which seem to be largely concerned with elaboration of the data furnished by the primary areas. The cortex surrounding each sense center may, perhaps, be considered the anatomical basis for perception, imagery, and the general combination and inter-

pretation of the sensory material from the body and its environment. But the grosser mental processes, as attention or reasoning, cannot be localized; all but the most elementary functions must be dependent on the activity of many various parts, that is, on the action of the brain as a whole.

No simple scheme of structure or action can serve to underlie such a highly complex organ as the human cerebrum. It has been pointed out that man's nervous system had a simple beginning, but that the nervous equipment of every animal in the scale of evolution has been adapted to the internal and external conditions to which that animal is subjected. It is by this successive adaptation throughout the animal series, and by modification in the individual from use and learning, that the tremendous development of the human brain has been effected. Only by a comprehensive study of these changes can we understand the intricacies of man's nervous mechanism; and to this further research, with due reference to more exhaustive texts, it is hoped the student will now turn.

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